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OUTLINES OF

NATURAL PHILOSOPHY

FOR SCHOOLS AND GENERAL READERS

BY

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ILLUSTRATED BY 216 ENGRAVINGS ON WOOD

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PREFACE.

THIS book is intended to supply the widely felt want of a work at once easy enough for a class reading-book and precise enough for a text-book. Great pains have been taken to make every statement as plain as possible, and to put every sentence into the form which will render it easiest to understand at first hearing. Familiar language whenever available has been preferred to the use of technical terms, as it is not desirable to encumber beginners with any names beyond what they need for conveniently expressing their ideas. Algebraic formulæ have been altogether excluded.

The woodcuts with which the work is profusely illustrated are not thrown in for mere ornament, but have been carefully designed and selected for the elucidation of the text, and are fully explained. To avoid distracting the attention of the reader, and at the same time permit reference when required, the technical names of pieces of apparatus have in many cases been indicated in the titles of the figures, though not used in the text. In like manner, in the index, several words are introduced which do not occur in the body of the work.

As regards completeness, the aim has been to include leading principles in so far as they can be made plain to beginners, and to omit such topics as, from their inherent difficulty, are better deferred to a later stage.

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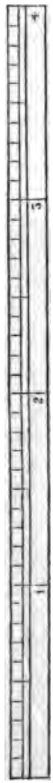
A DECIMETRE DIVIDED INTO CENTIMETRES AND MILLIMETRES.



INCHES AND TENTHS.

The METRE is about one ten-millionth of the distance from the equator of the earth to one of the poles, and is equal to 3·281 ft. or 39·37 in. The DECIMETRE is one-tenth of the metre; and the cubic decimetre is the LITRE, which is used for the measurement of capacity in the case of liquids and gases. The CENTIMETRE is the hundredth of the metre, and is about ·4 of an inch, or $\frac{1}{30\frac{1}{2}}$ of a foot. The MILLIMETRE is the thousandth of the metre or about $\frac{1}{25}$ of an inch.

The annexed scale contains 10 centimetres each divided into 10 parts, which are millimetres.

The French system of weights is founded on the centimetre. A CUBIC CENTIMETRE OF COLD WATER weighs ONE GRAMME, so that the volume of any quantity of cold water expressed in cubic centimetres (c.c.) is the same as its weight in grammes, and the weight of any body is equal to its volume in c.c. multiplied by its specific gravity (the specific gravity of cold water being 1).

Water has the peculiarity of contracting as it is warmed from 0° C. to 4° C., and then expanding as it is still further warmed, so that it occupies less space (or is more dense) at 4° C. than at any other temperature. It is at or very near this temperature that the weight of a cubic centimetre of water is exactly a gramme.

A cubic foot of water weighs a little less than 1000 oz. or 62½ lbs., and a gallon of water weighs 10 lbs.

A cubic decimetre of water at 4° C. weighs 1 KILOGRAMME or 1000 grammes, which is about 2·2 lbs. avoir.; 1 gramme is about 15·4 grains or $\frac{1}{28\frac{1}{3}}$ of an ounce avoir.

NATURAL PHILOSOPHY
FOR SCHOOLS.

CHAPTER I.—INTRODUCTORY.

1. NATURAL PHILOSOPHY in its broadest sense is the science which treats of the properties of matter.

2. There are some properties which belong to all kinds of matter alike, without distinction of degree.

One of these is the property of **inertia**, which may be thus stated:—Every body which is once at rest tends to remain at rest, and every body which is once in motion tends to continue moving with uniform speed in a straight course. Motion in a straight line with uniform speed is the only motion that a body can have if left to itself, and not pushed or pulled by other bodies.

Whenever a body at rest begins to move, or a body in motion moves in a curve, or moves faster or slower, it exhibits the "tendency" of which we have spoken, by offering resistance. A heavy garden-roller on a level pavement starts slowly and gradually when we pull it, and we feel it pulling us backwards as we pull it forwards. Again, when we have given it a good speed and try to stop it, we feel it pushing us forward as we push it in the backward direction, and we cannot stop it all at once. This illustrates the tendency to resist change of speed. The tendency to resist change of direction—that is, to resist anything which produces deviation from a straight line—is illustrated by swinging a weight round

in a horizontal circle by means of a string which we hold in our hand. We feel the weight pulling our hand outwards towards the circumference of the circle.

3. Another property possessed by all matter alike is **gravitation**, or, in common language, **weight.** Weight, as we know it in its most familiar form, is *tendency towards the earth;* but Newton discovered that there is a similar tendency towards the moon, towards the sun, towards the planets, and towards all matter whatever. All matter attracts all other matter. The force of this attraction depends partly on the magnitudes of the attracting masses and partly on their distance apart. When the distance between two bodies is very great compared with the size of the bodies, so that they may be regarded as mere particles, the force diminishes as the distance increases, in such a manner that at double distance there would only be one-fourth of the force; at threefold distance, one-ninth of the force, and so on—that is to say, the force varies inversely as the square of the distance.

When the two bodies are spheres, the same rule can be applied even when the bodies are near, the "distance" being in this case the distance between the centres of the spheres. The earth may be regarded as a sphere, and hence the force with which it attracts a body at its surface is four times as great as the force with which it would attract the same body if raised to a height equal to the earth's radius; for it would then be at the distance of two radii from the centre instead of only one. The distance of the moon from the earth's centre is about 60 radii of the earth, and hence the force with which the earth attracts a body on the moon is only $\frac{1}{3600}$th of the force with which it would attract the same body if at the earth's surface.

4. There are two ways in which the quantities of matter

in different bodies may be reckoned and compared. We are not speaking now of two pieces of matter of the same material, for in this case the comparison presents no difficulty. We are speaking of the comparison of two different substances; for example, a ball of iron and a ball of lead.

One way would be to compare the resistances which they offer to the same change of motion; for example, to compare the horizontal pulls which they exert when swung round with the same velocity in horizontal circles of the same size, and to say that the one which exerts the greatest resistance contains the most matter.

The other way would be to compare the forces of gravitation which they exert upon the same body at the same distance; or, what amounts to the same thing, to compare the forces with which they are themselves attracted by the same third body; for it is found to be universally the case, in every kind of pull or push, whether it be gravitational attraction, or magnetic attraction, or electrical attraction, or the pull of a string or the push of a stick, that the pull or push is a *mutual* force between two bodies, both bodies being equally pulled or equally pushed. In comparing two bodies at the earth's surface, we can compare the forces with which they are attracted by the earth. These forces are what we call their **weights.**

5. It has been found by careful experiments that these two ways of comparing matter agree exactly. Two bodies which offer the same resistance to change of motion have also the same weight.

As it is somewhat of a liberty to talk of the "quantity of matter" being the same when the substances are different, the word **mass** is used instead. Two bodies which offer equal resistances to change of motion are said to be equal in "mass" or to "have equal masses;" or the

two bodies themselves are often spoken of as "equal masses." The experimental fact which we have just asserted is accordingly expressed by saying that *bodies of equal mass are of equal weight;* and it will be equally true to say that bodies which have equal weight have equal mass.

6. The two ideas *weight* and *mass* are very much mixed up together in popular language and thought. Pounds, ounces, tons, and so forth, are sometimes employed as units of *weight* in the strict sense of the word, as when we speak of steam exerting a pressure of so many pounds per square inch, or of a rope being strong enough to bear a weight of so many tons; but more frequently these denominations are employed as measures of *quantity of matter*, as when we speak of a pound of sugar or a ton of coal. In this latter application the pound and ton are units of *mass.*

It is also to be remarked that if we take a piece of matter—say a pound of iron—and carry it about to different places on the earth's surface, its mass remains unaltered, but its gravitating force towards the earth varies, being greatest at the poles and least at the equator. If it were carried to the distance of the moon, its gravitating force towards the earth would be only $\frac{1}{3600}$th of what it was at first, while its mass would be unaltered. Thus a round piece of brass used for weighing, and called a "pound weight," is, strictly speaking, a standard of mass; it has exactly the same mass everywhere, but not exactly the same weight. Its weight, though variable, is always called by the same name—a pound—and as it is seldom that very exact measures of force are required, the slight inexactness involved in this use of the same name for slightly unequal forces has no practical inconvenience in ordinary life.

7. Density is closely connected with mass. If we take a cork and squeeze it to half its original size, we double its density. If we pump out half the air from the receiver of an air-pump, we halve the density. If we compress 20 cubic feet of air into a space of 1 cubic foot, we increase its density twentyfold. The densities of two substances are proportional to their *masses* when we compare equal volumes of both, and a body is said to be of uniform density when equal volumes in all parts of its substance have equal masses.

Bearing in mind the relation above pointed out between mass and weight, it is clear that a *dense substance* is the same thing as a *heavy substance*. Gold and platinum are about 20 times as dense as water—that is to say, they are about 20 times as heavy when compared bulk for bulk.

Gases have exceedingly small density compared with liquids and solids, and their density can be enormously altered by compressing them or allowing them to expand. The air which we breathe has about $\frac{1}{800}$th of the density of water; but it has often been compressed to 20 or 30 times its ordinary density, and rarefied till it has only one-thousandth or even one-millionth of its ordinary density.

8. Constancy of quantity, or constancy of *mass*, is a universal property of matter. When we burn a piece of wood, part of it combines with the oxygen of the air and goes off in the form of gas, part of it is water and goes off as steam, some small solid particles are carried off by the draught in the form of smoke; these are of combustible material (carbon), but not so readily combustible as some other portions; and a third portion remains in the form of ash. If we could catch all the gaseous products and weigh them along with the smoke and ashes we

should find the total weight to be greater than that of the original wood, because some oxygen from the air has been added. If the combustion of the wood is conducted in a closed air-tight vessel, the weight of the vessel and its contents will be exactly the same at the end as at the beginning.

In the growth of a plant all the additional matter which it gains comes to it from the soil and air, and is so much taken from them. There is no gain and no loss of mass on the whole in any operation or process whatever, whether of nature or art.

Chemistry goes further, and shows that all known substances are composed of some sixty simple substances or *elements*, and the quantity of each element remains always unchanged. No such thing as creation or destruction of an element ever occurs, nor is one element ever transmuted into another.

9. There are other properties which are possessed in very different degrees by different kinds of matter. A ball of steel retains its shape, as far as we can see with the naked eye, even when we squeeze it in a vice. A ball of lead similarly treated is permanently flattened. A ball of india-rubber is flattened for the time to a very large extent, but recovers itself when released. These differences of behaviour illustrate differences of **elasticity** and differences of **rigidity**. A body which is very difficult to force out of its original shape is called very *rigid*, and a body which instantly recovers its original shape when released is called very perfectly *elastic*. A body which can be very much distorted and yet will instantly recover itself—like india-rubber—is technically said to have *very wide limits of elasticity;* while such a substance as wrought iron, which remains permanently distorted if you bend it to any visible extent, is said to

have *very narrow limits of elasticity.* The subject of elasticity as regards solid bodies is very intricate. If we take several wires of the same size but of different metals we find that their resistances to stretching are not proportional to their resistances to twisting. It is thus necessary in accurate investigations to distinguish various kinds of elastic resistance, and their discussion constitutes an important branch of applied mathematics.

Most substances when pulled out lengthwise shrink in diameter, so that though their volume is increased it is not increased so much as their length; and in like manner when compressed endwise they swell in diameter. Cork is an exception. Even when compressed to half or a quarter of its original length its diameter remains unchanged. Its volume is therefore diminished in the same proportion as its length. India-rubber, on the other hand, alters its diameter so much that its volume is not changed at all. However much we pull or squeeze it out of shape its volume remains sensibly unchanged.

10. Liquids and gases offer no resistance to change of shape, but they resist compression. This is the only elastic resistance which they exert, and it is sometimes called *elasticity of volume.* It is enormously greater for liquids than for gases, being about twenty thousand times as great for water as for air.

Experiments on the compression of liquids are usually conducted with an apparatus like that shown in fig. 1. The second part of the figure shows on a larger scale a portion of the first. This portion consists of a glass vessel with a long narrow neck. It is filled with the water which is to be compressed, and a small drop of mercury is passed into its neck, where it is held up by friction, and serves as an index to show when the water moves up or down in the neck, for if the water moves it

carries the mercury with it. If we were to apply pressure to the outside of the vessel only, the capacity of the vessel would be diminished and some of the water would escape at the top. The water in the neck would accordingly rise, carrying the index with it. On the other hand, if a piston, fitting watertight, were pressed down into the neck so as to force the water before it, the index would fall, partly perhaps because of the compression of the water, but partly also because the vessel would be enlarged by the strong pressure within it. What is actually done is to place this vessel inside the larger one, as shown in the figure, and fill up with water. The large vessel is made of very thick

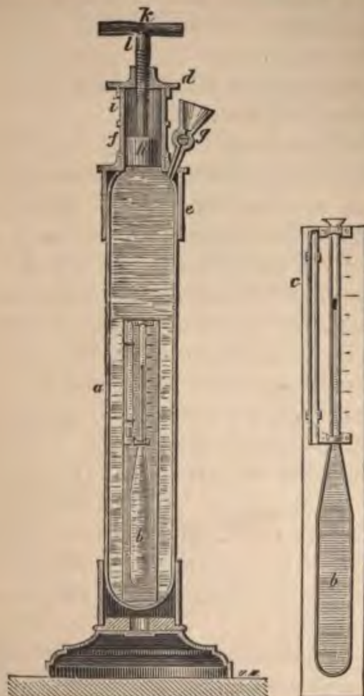


Fig. 1.—Œrsted's Piezometer.

and strong glass so that it can bear strong pressure in its interior without breaking. This pressure is produced by screwing down the piston at the top, and as we put on pressure and take it off again we see the mercurial index descend and spring up again. Its descent shows

that the water in the vessel is reduced to smaller volume; and more than this, it shows that the water is more compressible than the glass of which the inner vessel is composed, for if they both shrunk equally they would still fit each other, and no movement would be seen. A glass vessel thus submitted to uniform strong pressure both within and without retains its shape unchanged, and is diminished in volume just like a solid lump of glass.

11. Strength, as a property of materials, means the power to hold together without breaking. There are different kinds of it.

Tenacity is that kind of strength which enables a wire to exert a strong pull without breaking. Steel wire, such as is used for the pianoforte, is in this sense the strongest substance known, and wrought iron is much more tenacious than cast-iron. Strength to resist crushing is a different quality, and is possessed by cast-iron in a higher degree than by wrought iron.

Hardness is that particular kind of strength which gives the power to scratch or cut and to resist being scratched or cut. Glass will scratch iron, and iron (at least pure wrought iron) will not scratch glass. Glass is therefore said to be harder than iron. The hardest substance known is diamond, which is crystallized carbon. It easily makes scratches and even deep cuts in glass, and will do this every day for years without losing its edge. Next to it comes corundum, or crystallized alumina, of which the ruby is one form. Some other precious stones, such as the sapphire, topaz, and emerald, are largely composed of alumina, as is also emery, so well known for its scratching powers, which cause it to be largely employed in the grinding of steel.

Another very hard substance is silica, which, when crystallized and clear, is called rock-crystal. Agate,

jasper, flint, and quartz are other forms of it. It is much harder than glass.

The hardness of steel depends very much upon whether it is cooled gradually or suddenly from a red heat. The more sudden the cooling the harder it becomes, and the operation of hardening steel by dipping it when red hot into a cold liquid is called *tempering*. All steel cutting instruments are tempered. The opposite process of softening by gradual cooling is called *annealing*, and in glass manufactories there are annealing ovens in which newly-made glass vessels are left for some days to cool down gradually from a red heat.

The hardening of a metal makes it brittle, and the opposite process of annealing makes it tough. Steel dies are engraved when soft, and are afterwards hardened before they are used for stamping. In the making of wire, which is done by drawing the metal in the cold state through a succession of holes each smaller than the preceding, it is necessary to anneal the wire after each drawing in order to restore its ductility and prevent it from breaking in the next drawing.

12. Atomic Structure.—As a crowd of men consists of separate individuals, or a heap of wheat of separate grains, or a chain of separate links, so there is reason to believe that all matter consists of separate atoms. The atoms of any one elementary substance are believed to be all of one size and exactly alike; and the atoms of one elementary substance are different from those of another elementary substance. Atoms are much too small to be seen even in our most powerful microscopes, but there are several phenomena which compel us to infer their existence. They are probably about as large in comparison with a drop of water as a cricket-ball or a foot-ball is in comparison with the whole earth.

In a compound substance of definite chemical composition, the atoms of the two or more elementary substances which compose it are combined in clusters, all the clusters being exactly alike, and these clusters are called **molecules.**

Heat in a substance consists in vibratory movement of its molecules, or, in the case of an elementary substance, in vibratory movement of its atoms; and when the heat is so intense as to produce light, an examination of the light by means of an instrument called the spectroscope gives definite information as to the quickness of vibration of the molecules or atoms.

Why it is that the atoms of certain substances attract one another and tend to form molecules of definite composition, is one of the puzzles which have not been solved, though some partial attempts have been made which are not altogether without promise.

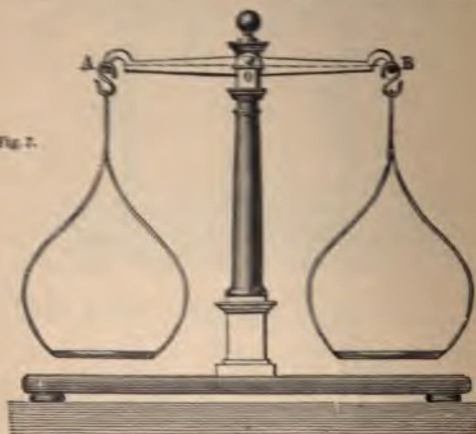
13. The extreme **divisibility** of matter may be illustrated in various ways.

When the smallest drop of blood that can be seen with the naked eye is flattened out between two pieces of glass, and examined by a pretty good microscope, it is seen to consist of a multitude of round flat bodies floating in a transparent liquid. The round bodies are called blood-corpuscles; they are between $\frac{1}{3000}$th and $\frac{1}{4000}$th of an inch in diameter, and their thickness is about a quarter of this. One cubic inch of blood contains about eighty times as many of them as there are people in the whole world. A microscope of high power enables us to see objects very much smaller than these, but still we are as far as ever from seeing the ultimate molecules of which matter consists.

The extreme divisibility of matter is well shown by dipping a paint-brush containing a little indigo or gam-

19. In the **ordinary balance**, or Pair of Scales, fig. 7, the beam A B turns about the sharp edge O of a steel wedge forming part of the beam, and resting upon two hard and smooth supports. There are two other steel wedges at A and B with their edges upwards, and upon these edges rest the hooks for supporting the scale pans.

Fig. 7.



The three points A O B are very nearly in one straight line, O being usually a very little above a line drawn from A to B. The distances A O and O B must be exactly equal.

Each scale pan with its contents places itself so that its centre of gravity is exactly under the knife-edge A or B which supports it; we may therefore regard the two weights as acting at A and B, and may regard the beam as a lever with its two arms equal. The beam itself, when the pans and hooks have been removed, ought to balance exactly about the edge O. The following is the best way to test whether a pair of scales is true.

First see whether the beam places itself horizontally when both scale pans are empty. If it does, then put a tolerably heavy weight into one scale pan, and into the other a cup of sand, adding or taking away sand till an exact balance is obtained. Then interchange the contents of the two pans and see if the balance is still maintained. If it is, the scales are true, but if it is not, one arm (that is one of the two distances O A, O B) is longer than the other, and if equal weights were put in the two pans, the one at the longer arm would go down.

Even with a false pair of scales a true weighing can be made if we have true weights, by employing the method called *double-weighing.* This consists in putting the body to be weighed into one pan and counterpoising it exactly with a basin of sand; then removing the body and finding what weights must be put in its place to produce the same effect. They will be equal to the true weight of the body.

20. The **wheel and axle,** of which a section is shown at fig. 8, consists of a large and a small cylinder, both having the same axis and turning together. Two cords are coiled, one round each cylinder, and weights hung at their free ends tend to turn the cylinders opposite ways. We may regard A B as a lever turning about a fulcrum at C the common centre of the two circles, and if the two weights are to balance each other, we must have the weight hanging from A multiplied by A C equal to the weight hanging from B multiplied by B C, or the weight which hangs from the wheel must be to that which hangs from the axle as the radius of the axle to the radius of the wheel. The radii A C and B C of the two circles are proportional to the circumferences, and these are equal

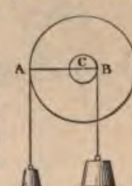


Fig. 8.

to the distances through which the two weights move (one downwards and the other upwards) in one revolution. Hence one weight multiplied by the distance it falls is equal to the other weight multiplied by the distance it rises.

It may be well here to point out the difference between the meanings of the words **axle** and **axis.** An axle is a real material thing of finite thickness; an axis is a mere mathematical line having no thickness whatever. When a body turns truly on an axle, the central line of the axle is the *axis.*

The **winch** used for raising buckets full of water from a well is equivalent to a "wheel and axle," the circle described by the handle taking the place of the "wheel."

Fig. 9 represents a **capstan,** with two bars, and men pushing at them, thus raising a weight by means of a rope which is wound upon the drum of the capstan.

Fig. 9.

Sometimes the bars are much longer than those represented in the figure, and there may be several of them. In order to calculate the force which is put upon the rope, we must multiply the force with which each man pushes by the distance of his hands from the axis; we must add these products together, and then divide by the radius of the drum on which the rope is being wound.

This rule can be justified from a consideration of the work done, in the following way. Each man walks in a circle pushing straight forwards as he walks. The work which he does in going once round the circle is the

horizontal force with which he pushes multiplied by the circumference of the circle. By making this calculation for each man, and adding the products, we obtain the work done in one revolution of the capstan. On the other hand the weight is raised a distance equal to the length of rope that is coiled upon the drum in one revolution, which we may take as being equal to the circumference of the drum. This length multiplied by the weight will be equal to the work done by the men. Since the circumferences of circles are proportional to their radii, this result agrees with the rule stated.

21. This is a very good example of what is called the *principle of moments*, which may be thus stated:—

When a body can turn about an axis, and forces are applied to different points of the body tending to carry them round the axis, either in one direction or the opposite, the forces will balance if, when we multiply each of them by its distance from the axis, and add the products, the total is the same for the forces which tend one way round as for those which tend the contrary way round. The product obtained by multiplying one of the forces by its distance from the axis is called the *moment* of this force about the axis.

22. Thus far we have made no mention of **friction.** Friction always tends to prevent motion. Thus, when men are raising a weight by means of a capstan, they have to do not only an amount of work represented by the raising of the weight, but a further amount of work sufficient to overcome the friction of the apparatus. The pressure which they must exert against the levers is therefore greater than it would be if there were no friction. On the other hand, when they are letting the weight down, or simply sustaining it, the pressure which they must exert is less than if there were no friction,

because friction tends to prevent the weight from running down.

These remarks are of general application to the friction of machines. Whenever we have calculated the relation between the force which we are to apply, and the resistance which it is to balance, without considering friction, we must increase the applied force if it is to overcome friction and produce motion; while on the other hand, if the force which we apply is merely intended to prevent motion, it may be smaller than if there were no friction.

23. Friction has an important bearing upon the subject of stored-up work, or energy, which has been briefly explained in art. 15. When we employ a machine to store up work by raising a weight, if there is any friction in the process a portion of the work employed in driving the machine will be wasted, so that the work stored up will be less than the work employed to obtain it. This looks at first sight like a diminution of the whole quantity of energy—contrary to the concluding words of art. 15. But further examination shows that what looks like a destruction of energy here is only a transformation. Heat is one form of energy, and the energy which has been lost in the mechanical form has been converted into heat. The quantity of heat produced by friction in different cases has been found to be exactly proportional to the amount of work consumed in producing it. In fact every foot-pound of work that is wasted in consequence of friction, produces just as much heat as would raise $\frac{1}{772}$ of a pound of water one degree Fahrenheit in temperature.

Chapter III.—PARALLEL FORCES.

24. Parallel Forces.—Two parallel forces must either be in the same direction or in opposite directions; for instance, if one of them acts vertically upwards, the other must either act vertically upwards or vertically downwards.

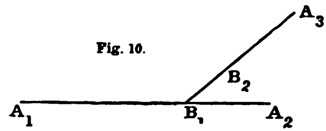
When any number of parallel forces balance one another upon the whole, if we add together those which act in one direction, and also add together those which act in the opposite direction, the two sums will be equal. For example, if a table with various heavy bodies on it stands on a floor, the upward pressures of the floor against the feet of the table must together be equal to the added weights of the table itself and the bodies resting on it. It will be remembered that by the general law of the equality of action and reaction, the upward pressures of the floor against the feet are equal to the downward pressures of the feet against the floor, so that what we have stated merely amounts to this—that the whole weight of the table and things on it rests on the floor.

So, if we have a lever with weights on its two ends, resting in equilibrium on a fulcrum, the downward pressure of the lever on the fulcrum or the upward pressure of the fulcrum against the lever, must be equal to the weight of the lever itself together with the two weights which it carries.

25. Centre of Gravity.—Suppose two heavy particles at A_1 and A_2, fig. 10, the particle at A_2 being twice as heavy as that at A_1. If we divide the joining line $A_1 A_2$ into two parts of which one is double of the other, the greater part being next the smaller weight (that is,

take B_1 so that $A_1 B_1 = 2 B_1 A_2$), then the two weights at A_1 and A_2 would balance each other about the point B_1; that is to say, if we imagine a lever $A_1 B_1 A_2$ without weight resting on a fulcrum at B_1 and acted on by the given weights at A_1 and A_2, this lever will be in equilibrium in every position, whether horizontal or inclined. This is what we mean when we say that B_1 is the centre of gravity of the two given weights at A_1 and A_2.

Fig. 10.



These two weights could always be balanced by a single force equal to their sum acting upwards at B_1; we may therefore say they are equivalent to a single force equal to their sum acting downwards at B_1; in other words the two weights at A_1 and A_2 can be collected at B_1 without rendering any change necessary in the supporting force. *Any two heavy particles have a centre of gravity, which divides the joining line in the inverse ratio of the weights of the particles.*

Now suppose a third heavy particle at A_3. We may replace the first two particles by a single particle equal to their sum at B_1, and we shall then have only two heavy particles, one at B_1 and the other at A_3. Their centre of gravity can be found as above; let it be B_2. Then B_2 is the centre of gravity of the three given particles at A_1, A_2, and A_3. We may then collect these three particles at B_2 and take in a fourth particle, and so we may go on till all the particles of a body have been included. Therefore every solid body has a centre of gravity—a point at which we may suppose all its weight collected without requiring any change in the supporting forces.

26. A heavy body can therefore be supported at a

single point as O, figs. 11, 12. All that is necessary is that the body be turned into such a position as to put its centre of gravity G directly under or over the point of support. If the body be supported at the centre of gravity itself, no particular position is necessary; it will be in equilibrium in all positions.

Fig. 11.

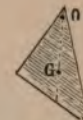


Fig. 12.

When the centre of gravity is directly *under* the point of support, as in fig. 12, the equilibrium is *stable*, that is to say, if we give the body a slight push it will only make small oscillations—and finally settle in the same position again.

When the centre of gravity is directly *over* the point of support, as in fig. 11, the equilibrium is *unstable*, that is to say, if we give the body ever so slight a push it will tumble completely away.

When the centre of gravity coincides with the point of support, the equilibrium is neither stable nor unstable, and is called *neutral*. If we move it a little it still remains in equilibrium.

27. In order to decide whether a heavy body will stand or topple over, when set down in a given position, it is sufficient to know whether a line drawn vertically downwards from the centre of gravity falls within the base; if it does, the body will stand. If it falls outside the base, the body will topple over towards the side on which the vertical lies. In the case of the three-legged table shown in fig. 13 we are to understand by the *base* the triangle formed by joining its feet, as shown by dotted lines in the figure; for if the table turned over it would have to turn round one of these lines.

28. When a body is hung by one point about which it

can swing freely, it places its centre of gravity vertically under the point of suspension, and this property can be used to find the centre of gravity of a piece of board in

Fig. 13.

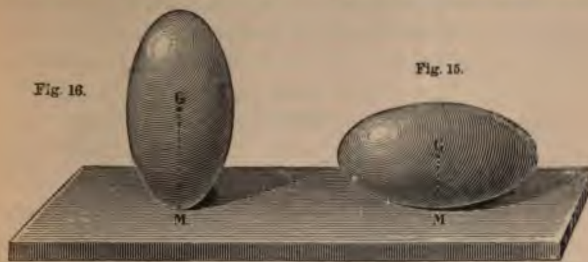
the manner represented in fig. 14. Suspend it from a point in or near its circumference, and suspend a plumb-line from the same point. Mark the position of the plumb-line on the board. Then suspend the board and plumb-line from another point, and mark the point where the new line intersects the old one. This point G, or rather a point opposite to it in the substance of the board—will be the centre of gravity, and if the board be laid flat it will be found to balance about G. Another plan is to shift the board to the edge of a table (which should be straight and sharp) until we find that the least further movement would make it fall over. Draw a line on the body marking the position of the edge. Then turn the body through a right angle, or nearly a right angle, and obtain another

Fig. 14.

line in the same way intersecting the former one. Their

Fig. 16.

Fig. 15.



intersection is the point about which the board will balance.

29. When an egg is laid upon its side on a level surface, as at fig. 15, it takes a position in which its centre of gravity G is exactly over the point of contact M at which the egg is supported. The equilibrium here is stable. Fig. 16 represents a position of unstable equilibrium, the centre of gravity being vertically over a point of contact M at one end of the egg. The centre of gravity is here in the highest position that it can have without the egg leaving the table, whereas in fig. 15 it is in the lowest position. The centre of gravity of a body always tends to get as low as it can. This is illustrated by the toys shown in the next three figures.

Fig 17.

In fig. 17 the two leaden balls are so heavy compared

with the figure that the centre of gravity of the whole body consisting of figure, rods, and balls together is a little below the toe on which it balances.

The toy in figs. 18, 19 consists of a hemisphere of lead

Figs. 18, 19.

with a light human figure fastened to it. The centre of gravity of the whole is somewhere between the centre of gravity of the hemisphere and the centre of the sphere of which it is the half. The height of the centre of the sphere is not altered by rolling, and the height of the centre of gravity of the hemisphere is least when the figure is upright. This is accordingly the position of stable equilibrium.

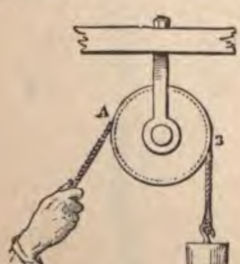


Fig. 20.

30. We shall now exemplify some of the foregoing principles by systems of pulleys. We shall suppose the pulleys to turn without friction. When a string is passed round a pulley and the two ends are pulled, the pulley will turn unless the two pulls are equal; for the two strings are at the same distance from the axis of the pulley, the distance of each being equal to the radius of the pulley.

In fig. 20, which represents what is called a *fixed pulley*—strictly speaking, a pulley turning on a fixed axis—the pull exerted by the hand must be equal to the weight sustained.

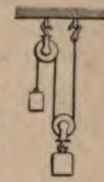


Fig. 21.

In fig. 21 the three portions of string exert equal pulls, and the pulls of the two right-hand ones are together equal to the weight which they support, that is to say to the weight which hangs from the lower pulley together with the weight of this pulley itself. Hence the force in each string is half of this weight. The other weight simply hangs from the end of the left-hand portion of string, and is therefore a direct measure of the pull in the string. This weight must therefore be half the other if the weight of the lower pulley can be neglected. More accurately it is half the sum of the lower weight and the weight of the lower pulley.

Fig. 22.

In fig. 22 there are in all six pulleys, three turning in an upper fixed block, and three in a lower movable block. One string passes round all, and therefore the force of tension is the same in all the seven portions shown in the figure. The lower block is supported by the combined pulls of six of these portions, which are parallel or very nearly parallel, and therefore each has to bear one-sixth of the weight supported. The pull which must be exerted by the hand upon the free end of the string is therefore one-sixth of the combined weights of the lower block and the mass which hangs from it.

If we compare the movements of the free end and of the weight which is raised or lowered, we shall see that

no work is gained or lost. In fig. 22, if the weight is raised one inch, each of the six strings which support the lower block is an inch shorter than before, therefore six inches of string have passed over the topmost pulley, showing that the hand has pulled the free end through a distance of six inches. The work done by the hand is the pull of the hand multiplied by six inches, and this is exactly equal to the weight raised, multiplied by one inch, because we have shown that the pull of the hand is one-sixth of the weight raised.

In fig. 23 there are four pulleys, three movable and one fixed. We shall neglect their weights. Then if we attend to any one of the three movable pulleys, we see that it is pulled upwards by two strings, each of which therefore bears half the downward force acting on the hook of the pulley. There are three strings—the left-hand one is stretched with a force equal to half the weight, the second with a force equal to a quarter of the weight, and the last with a force equal to an eighth of the weight, this last string being the one that is held in the hand. The hand has therefore to bear one-eighth of the weight. If the weight rises 1 inch, the second pulley from the bottom rises 2 inches, the third 4 inches, and the hand descends 8 inches.

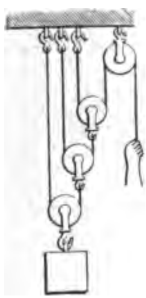


Fig. 23.

CHAPTER IV.

RESULTANTS AND COMPONENTS.

31. Resultant of Forces.—We have seen that the whole force of gravity upon a body can be balanced by an upward force applied at the centre of gravity, or at any point in the same vertical line with the centre of gravity. We may therefore say that the whole force of gravity on a body is *equivalent to a single force*, acting vertically downwards, and applied at any point of this line. This imaginary single force is called the **resultant** of all the forces of gravity on the different particles of the body. Parallel forces applied to a body always have a *resultant*, that is a single force which would be equivalent to them, and might be substituted for them without producing any disturbance of equilibrium or any change of motion.

32. There is another case in which forces acting on a body always have a single resultant, and that is when the forces act in lines which meet in a point; for it is clear that the body could be prevented from moving by a single force applied at the point. A force equal and opposite to this single force is the resultant.

The magnitude and direction of this resultant force can be found by a beautifully simple construction. Represent the forces by straight lines AB, BC, CD, DE (fig. 24), parallel to the given forces and representing them in magnitude on any convenient scale (for example, an inch may represent a pound). We shall thus obtain a crooked line, such as A B C D E, and a straight cut from the beginning to the end of it (that is A E in the figure) will represent the resultant. The order in which

the forces are taken makes no difference; the line A E will be the same whatever order we adopt.

33. The most common case is where we have only two forces, and want to find their resultant. Suppose they act along the lines A B, A C, fig. 25, and are represented by these lines in magnitude. Then if we complete the parallelogram A B D C, the opposite sides will be equal, and we may either take the crooked line A B D or the crooked line A C D as representing the two given forces. In either case A D is the straight cut which represents their resultant. Thus we have the rule called the **parallelogram of forces**:—

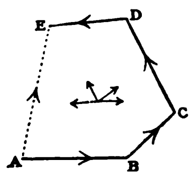


Fig. 24.—Resultant of Forces at a Point.

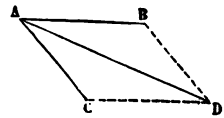


Fig. 25.—Parallelogram of Forces.

If two forces acting at a point are represented by two adjacent sides of a parallelogram, the diagonal represents their resultant.

In order to guard against taking the wrong diagonal, observe that if one of the forces tends from A towards B, and the other from A towards C, then the diagonal A D which passes through A is the one which is to be taken, and the resultant force tends from A to D.

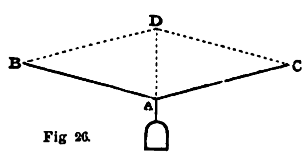


Fig 26.

34. A few illustrations will help to show the mode of applying the parallelogram of forces to actual cases. Suppose two nails B, C, fig. 26, fixed in a wall at the same height, the ends of a string BAC fastened to them, and a weight attached to the middle of the string. Complete the parallelogram A B C D, then A B and A C

represent the pulls of the two portions of the string, and A D represents their resultant, which is equal to the weight supported at A.

We can see from this that if the nails are put further apart, the point A being kept at the same distance beneath them as at present, and the weight unchanged, the pulls in the string will be stronger, although only supporting the same weight. The scale of representation will in fact be unchanged, since the same length A D will still represent the same weight. The pulls in the two portions of the string will therefore be increased in the same proportion as their lengths—in other words, the tension of the string will be directly as its length.

If, on the other hand, while altering the distance between the nails, we at the same time alter the height of A so as to keep the shape of the figure unchanged, the tension of the string will be unaltered.

35. Again, suppose we hang a weight by a string from a hook in a beam, and then pull the weight to one side by a second string, let us see how the pulls in the two strings will compare with the weight.

Let B, fig. 27, be the position of the hook, A B the first string, and A H the second string, which we shall suppose to be horizontal. Draw a horizontal line through B, and a vertical line through A, till they meet in D, and draw D C parallel to B A, meeting the second string in C. Then A D represents the weight, and A B, A C the pulls in the two strings. Since A D B is a right angle, we have $AB^2 = AD^2 + AC^2$, which shows that

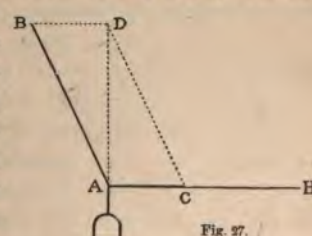


Fig. 27.

the pull in the first string is always greater than the weight.

If the first string is 13 inches long, and the weight is drawn aside 5 inches, we have:—

$$13^2 = AD^2 + 5^2$$
$$\text{whence } AD^2 = 169 - 25 = 144$$
$$AD = 12$$

therefore the first string exerts a pull of $\frac{13}{12}$ of the weight, and the second string a pull which is $\frac{5}{12}$ of the weight.

36. We shall now apply these principles to the *inclined plane.*

Suppose a heavy body to be resting on an inclined plane without friction, and to be kept from running down by a string which is parallel to the incline.

Since there is no friction, the mutual pressure between the body and the plane is at right angles to the plane. The body is acted on by this force, also by the pull of the string, which is parallel to the plane, and by gravity, which is vertical.

We may regard any one of these three forces as equal to the resultant of the other two. Let us take the weight of the body as the resultant, then the parallelogram of forces will be right-angled, and will have its diagonal vertical. This diagonal M P, fig. 28, represents the weight, the side P N, parallel to the plane, represents the pull of the string, and the side P T at right angles to the plane, represents the pressure exerted by the plane. The resultant of P N and P T is along P M, and balances the weight.

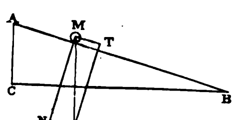


Fig 28.

37. It is often convenient to *resolve* a given force into two *components*, that is to say, to find two *forces of which*

it is the resultant. Thus, in the case just considered, we have in fact resolved the weight into two components, one parallel, and the other at right angles to the plane. If we draw a triangle (M N P or M T P) with two of its sides parallel to the two components, and its third side in or parallel to the direction of the given force, the lengths of its sides will show us the magnitudes of the components as compared with the given force.

38. Comparing the triangle M T P with the triangle A C B, in which A B is the length of the inclined plane, A C its height, and C B its base, we see that the angles at T and C are right angles, and the angles T M P, B A C, equal; hence the triangles are similar. We may consequently use A B instead of M P, and A C instead of M T. Thus we obtain the following result, which is easily remembered:—

When the weight is supported by a force parallel to the inclined plane, this force is to the weight as the height of the plane to the length.

39. The inclined plane serves as an illustration of the principle of work, and throws some additional light upon the way in which that principle is to be applied.

Suppose the heavy body to be drawn up the whole length of the plane by means of a string parallel to the plane. Then the work done by the pull in this string is computed by multiplying the pull by the length of the plane. On the other hand, to compute the work done against gravity, we must multiply the weight of the body by the height of the plane; and we see at once from the concluding sentence of the preceding section, that this product is equal to the former one.

In computing work done by gravity, or work done against gravity, horizontal motion does not count. Gravity neither tends to assist horizontal motion nor to pre-

vent it, and when the motion is in a slanting direction we are to take account only of the difference of levels.

There is a third force, namely, the *resistance of the plane*, which assists in maintaining equilibrium when the body is at rest; but as it is at right angles to the direction of motion, it does not urge the body either up the plane nor down the plane. It is therefore to be regarded as doing no work. In computing work done by forces upon a moving body, no account is to be taken of any forces which act at right angles to the motion.

40. We have supposed the inclined plane to be frictionless. If there is friction it will oppose the motion. The force of friction acts along the plane, and this force multiplied by the distance that the body moves is so much work done against friction, which must be added to the work done against gravity, and the total thus obtained will be equal to the work which must be done in pulling the string.

On the other hand, when we let the body slide down the plane, keeping it in check by the string, friction opposes the tendency of the body to run down, and thus renders our duty easier. When we want to prevent motion, or to prevent it from becoming too rapid, friction helps us, and when we want to produce or to quicken motion, friction hinders us.

41. In the actual use of inclined planes to assist in raising weights, rolling is usually employed instead of sliding, and thus friction is very much diminished. This remark is applicable to the drawing of a carriage up a hill. If the gradient is 1 in 20, that is a rise of 1 foot for every 20 ft. measured along the road, a pull equal to $\frac{1}{20}$ of the weight would just suffice to keep the carriage moving at a uniform pace if there were no friction at the axles, no inequalities on the surface of the road to be

surmounted, and no crushing down of the road. Owing to these various sources of friction (of which the two latter are usually the most important), the force required to draw the carriage up the hill is sensibly greater than that which would suffice to hold it from running down.

42. In raising a cask out of a cellar by rolling it up planks, an additional advantage is obtained by applying the force at the surface of the cask. The case is the same as when men urge a carriage forward by pushing at the circumference of the wheels. The highest point of a wheel moves twice as fast as the centre, and a force applied at the highest point will therefore produce the same effect as a double force applied at the centre. If, as is often the case, a rope is employed which is wound half round the cask and has its two straight portions parallel to the incline, one end of the rope being fastened and the other pulled by hand, the force with which this end must be pulled is only half that given by the ordinary rule for the inclined place. The cask serves as a pulley for raising itself, and the free end of the rope has to be pulled through double the distance that the cask rolls.

43. The *wedge* may be regarded as an application of the principle of the inclined plane; but the driving force, instead of being applied parallel to one face, usually bisects the angle between the two faces, the section of the wedge having the form of an isosceles triangle with the vertical angle very acute. In driving in the wedge, it is clear that while the wedge advances a distance equal to its own length it produces a separation equal to its thickness at the base; hence we know at once by the principle of work that, apart from friction, the driving force must be to the resistance which is forced back as the thickness of the wedge to its length.

In the absence of friction, the wedge would spring out as soon as the driving force ceased to act. In the actual use of wedges friction is of great service. A nail driven into wood may be regarded as a wedge, and is only held in the wood by friction. The driving of a wedge, whether it be a nail or a wedge for splitting wood, is usually accomplished by hammering. A blow of a hammer applies an exceedingly strong force for an exceedingly short time. This strong force easily overcomes the resistance of friction to forward motion; and when the wedge has been advanced by the blow, friction, and friction alone, prevents it from coming back. The work that is done by the human arm, in getting up speed in the hammer, with an addition from gravity if the blow be struck downwards, is equal to the work which is got from the blow in the shape of resistance pushed back and friction overcome, if we leave out of account the small amount of work which is wasted in producing vibration and in beating the wedge slightly out of shape.

44. The *screw*, fig. 29, like the wedge, is closely allied to the inclined plane, and also, like the wedge, involves in its actual use a large amount of friction. Whether we employ it to pull two things together, as in screwing down the lid of a box and in squeezing together the jaws of a vice, or to push by one end as in a screw-press, it is friction that prevents it from unscrewing when we cease to urge it forwards. Without friction it would instantly shoot back until the pressure was completely relieved.

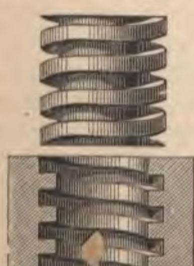


Fig. 29.

In the screw-press, fig. 30, and the vice, the screw is provided with a lever handle which multiplies the driving

force; and even in driving a screw with a screw-driver the handle is so much larger in diameter than the screw that a considerable multiplication is obtained. Two driving forces are usually employed to produce rotation, one at each end of the lever handle in the screw-press, and one at each side of the handle in the screw-driver, besides a third force, which, in the case of the screw-driver, is applied not to produce rotation, but to prevent the tool from slipping out of the notch. This third force, though often very considerable and adding much to the labour of driving, does very little "work" in the technical sense in which this term is used in mechanics. Its work in one revolution is computed by multiplying it by the distance that the screw penetrates in one revolution, which is a very small distance. If the other two forces are equal and act at equal distances from the axis of rotation, we must add them together and multiply by the circumference of the circle which they describe, to obtain the work which they do. The work done by the driving forces in one revolution is equal to the work done against friction, together with the useful work done by the screw in pushing or pulling. Leaving friction out of account, and taking the case of the screw-press or vice, where the driving forces do not press the screw home but simply turn it, the sum of the two driving forces, multiplied by the circumference of the circle which the hands of the operator describe, will be equal to the pushing

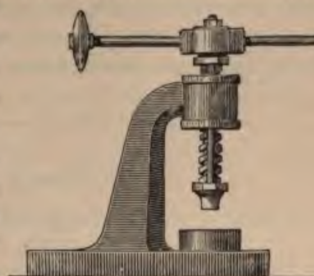


Fig. 30

or pulling force exerted by the screw, multiplied by the distance between the threads, this latter being obviously the distance that the screw advances in one revolution. As this is an exceedingly small distance compared with the circle described by the hands, the push or pull exerted by the screw is exceedingly great compared with the driving forces applied to the handles.

CHAPTER V.

MOTION UNDER THE ACTION OF FORCE.

45. Laws of Falling Bodies.—When a heavy body is dropped from a height, it falls faster and faster until it strikes the ground. At the end of 1 second it has a velocity of 32 ft. per second; but its average velocity for the whole of the first second is only 16 ft. per second, and the distance that it falls in the first second is therefore 16 ft. At the end of 2 seconds its velocity is 64, but its average velocity for these 2 seconds is 32 ft. per second, and the distance that it falls in the 2 seconds is therefore 64 feet, or 4 times the space in the first second. In 3 seconds the distance fallen is 9 times 16, or 144 ft., and so on, the multiplier being always the square of the number of seconds.

These statements are tolerably exact for such bodies as good-sized pebbles or bullets, up to a distance of a few hundred feet, and for a large block of stone they would remain true for still greater distances. In these cases the resistance of the air does not make much difference. They are not true for such a body as a feather falling in air, but if the air were removed a feather would fall just as fast as a stone or a piece of lead. This is usually

roved by putting a feather and a piece of lead into a ong tube from which the air can be pumped out, and hen inverting the tube so that the lead and the feather all from one end of it to the other.

When we want to throw a stone upwards to any par-icular height, we must throw it with exactly the same elocity with which it would strike the ground if it fell rom that height. In other words, a stone falls back vith the same velocity with which it was thrown up.

46. If the heavy body, instead of being dropped, is hrown horizontally, it moves in the manner represented n fig. 31. To understand vhat it does, we may con-eniently regard its motion s consisting of two parts, *orizontal motion* and *vertical notion.* Its horizontal velo-ity will be uniform, and its ertical motion will be the ame as if it had not been hrown but simply dropped. The figure 0 is placed at he starting-point, through vhich two straight lines are lrawn, one vertical and the ther horizontal. On the ertical line the length from

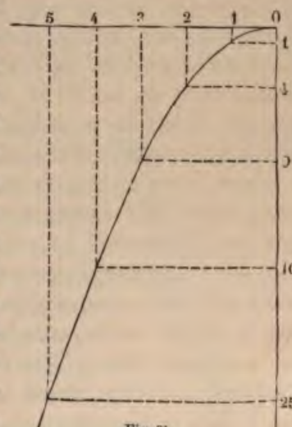


Fig 31.

) to 1 represents 16 ft., the length from 0 to 4 is 4 times 16 ft., and so on. On the horizontal line the distance rom 0 to 1 represents the distance in one second due to he velocity of projection; for instance, if the body is hrown with a velocity of 40 ft. per second the distance rom 0 to 1 represents 40 ft. The figures 0, 1, 2, 3, 4, 5 are quidistant, and are placed at the positions which the

body would occupy at the end of successive seconds if it moved in a straight line with its initial velocity continued uniform. We are to draw vertical lines through these points and horizontal lines through the other set of points, as is done in the figure, and the points of meeting will represent the actual positions of the falling body at the ends of the successive seconds.

The path of the body is a curved line, called a *parabola*. If the body be thrown back from any point in its path with the same velocity with which it arrived there, it will retrace its path upwards; and supposing no obstacle to be in the way it will pass through 0 and descend in an exactly similar curve on the other side. A stone or a cricket-ball when thrown describes a parabola, except in so far as the resistance of the air may slightly interfere with its movement. In the case of bomb-shells, cannon-balls, and musket or rifle bullets, the velocity is so high that the resistance of the air tells very much, and causes a considerable loss of velocity; but it is important to remark that however great the velocity of discharge may be, the path will never be quite straight. It is always a curve, though it may be so flat that a portion some yards long would easily be mistaken for a straight line. This is allowed for in taking aim with rifles. The barrel is always pointed above the mark, and is turned up more and more as the distance increases.

47. The greater the velocity of discharge the flatter the curve will be; and if the projectile were above the earth's atmosphere so as to move without resistance, a certain velocity, which is easily calculated, would make its curvature as flat as that of the earth's surface, so that it would circle round the earth and be a satellite.

The force which keeps any satellite revolving round

its primary is precisely similar to the force which determines the course of a cricket-ball as it is travelling through the air; and the movements of the primary planets themselves in their courses round the sun are similarly explained.

48. Centrifugal Force. We must now say a little about what is commonly called *centrifugal force.* We shall first give some examples of it, and then explain what it is.

When a stone is swung round in a sling, the strings are kept tight by the tendency of the stone to get away. It is to be observed, however, that when the stone does get away it does not fly outwards from the centre of the circle it has been describing, but goes off at a tangent.

A rapidly revolving wheel in like manner throws off water or mud in the direction of a tangent to the wheel.

Again, if we are travelling in a railway train, and suddenly come from a straight part of the line to a sharp curve where the line turns round to the right, we find ourselves thrown to the left side of the carriage—that is, towards the outside of the curve.

Fig. 32.

Again, if a vessel of water (fig. 32) is rapidly rotated round its axis (the dotted line in the figure), the water in the vessel, instead of having a level surface, will be concave—the middle will be lower than the outside; and if the rotation is very rapid the hollow may even extend down to the very bottom, and leave a dry place in the centre with a circular wall of water all round it.

All these effects are popularly attributed to *centrifugal force.* Now let us see how they are to be explained.

49. Let A D (fig. 33) be the direction in which a carriage has been proceeding till it comes to the curve A B. If a person is standing on the floor of the carriage his feet are compelled to follow the curve, and his body (if he makes no special effort) continues moving along A D, thus giving him a tendency to fall over to the left, because his feet are carried from under him to the right. He feels as if he were thrown towards the left side of the carriage, whereas, what really happens is, the left side of the carriage moves towards him.

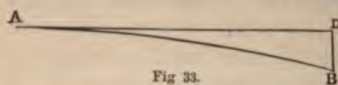


Fig 33.

The same figure may represent a small portion of the path of the stone in the sling. A D is the direction in which the stone would move if it were released at A, but the pressure of the leather against it makes it move in the curve. The pressure of the leather must be just as much as would move the same stone from rest through the distance D B in the same time. The string has to exert a pull equal to this pressure, and is therefore kept tight.

In like manner the sides of the whirling vessel in fig. 32 press the water; and the water is squeezed up by this pressure for the same reason that, when a glass half full of water is suddenly pushed forward, it rises against the side from which the push comes.

50. Our next subject is the **pendulum.**

In studying the laws of pendulums experimentally, we may begin by employing leaden bullets suspended by threads of various lengths. We shall find that lengthening the thread retards the vibrations, and that if we want to make the vibrations twice as slow we must make

the thread four times as long; to make them three times as slow we must make the thread nine times as long, and so on; that is, the length of the thread must be inversely as the square of the number of vibrations made in a given time.

We shall also find that the quickness of vibration is hardly affected at all by the extent of the swing, as long as this is kept within moderate limits. For instance, if the thread is a yard long, we shall not be able to detect any difference when we make the bullet swing first to one inch on each side of the lowest point, and secondly to two inches on each side. This is the property which makes the pendulum so useful as a time-keeper.

Fig. 34.

The pendulum of a clock has a heavy weight M (fig. 34) called the *bob*, near the lower end, and a screw V for raising or lowering the bob to a small extent. Screwing up the bob makes the pendulum go quicker. The rate at which a clock goes chiefly depends on its pendulum; if the pendulum is taken off, the clock runs on more than a hundred times as fast as it ought to do. The pendulum checks the clock by means of a wheel called the escapement wheel, which can only advance one tooth for each double swing of the pendulum. When a clock is found to be losing, the bob of its pendulum must be screwed up, as this will make the pendulum go quicker; when it is gaining, the bob must be screwed down.

51. When a pendulum is suspended apart from a
and mounted in such a way as to have the least p
friction at its supports, it will make some hundr
thousands of vibrations after being fairly set swi
before it comes to rest. By counting a large num
vibrations, and observing the total time which
occupy, the quickness of vibration is very accu
known; and it is from observations of this kind th
knowledge of the variations of gravity over the
surface is chiefly derived; for a pendulum vibrates
where gravity is strongest. If a pendulum were c
to a planet where gravity is four times as strong as
earth, it would vibrate twice as fast.

HYDROSTATICS.

Chapter VI.—PRESSURE OF FLUIDS.

52. We now come to that branch of Dynamics which relates to **fluids,** under which name are included both liquids and gases. It is called **Hydrostatics,** and that part of it which relates to gases is called **Pneumatics.**

53. One of the fundamental properties of a fluid is that the pressure at any point in it is the same in all directions. The air in a room presses against every surface exposed to it—whether the floor, the ceiling, the walls, or the surfaces of objects in the room, with a force which amounts to nearly 15 lbs. for each square inch of surface, or rather less than a ton for each square foot. If we have a piston one square foot in area which can travel air-tight in a cylinder, and there is vacuum on one side of it, while the other side is exposed to the pressure of the air, a force of nearly a ton will be required to hold the piston in its place and prevent it from moving towards the side on which the vacuum is; and this will be equally true whether the cylinder is fixed in a vertical, a horizontal, or an oblique position.

The *amount* of pressure exerted by the atmosphere upon a plane surface is proportional to the area of the surface. It can be expressed as so many *pounds.* But the *intensity* of the pressure is the same whether the area be small or large, and can be expressed as so many *pounds per square inch.* The word *pressure* alone sometimes means amount of pressure, but more frequently intensity of

pressure, and we must judge in each case by the context which is meant. When "the pressure at a point" is spoken of, it is intensity that is meant, and we shall generally employ the word *pressure* in this sense.

A pressure equal in intensity to that exerted by ordinary air is often called "a pressure of one atmosphere," or sometimes simply "an atmosphere," and other pressures are often expressed as so many atmospheres. Pressures up to 5 or 10 atmospheres are very common in steam-engines.

Though ordinary air is at a pressure of about 15 lbs. per square inch, it must not be supposed that this particular pressure is an inherent property of air. By compressing air we can make its pressure many times greater, and by allowing it to expand we can make its pressure many times less. We shall return to this subject later.

54. We have now to speak of the pressure of **liquids.** If the upper surface of a liquid is exposed to the air, as is usually the case, the pressure just beneath the surface is a little greater than atmospheric, and the deeper we go down the greater the pressure becomes—a fact well known to swimmers, the increased pressure being very sensible in their ears when they dive deep. The pressure increases at the rate of about one atmosphere for every 34 feet that we go down; so that at 34 feet deep it is two atmospheres, at 68 feet three atmospheres, and so on.

55. The reason why the pressure increases with the depth is because the liquid is heavy. If we have a cylindrical jar filled to any depth with liquid, the bottom has to bear the whole weight of the liquid; for the pressure at the sides is horizontal, and there are no vertical forces acting on the liquid except its own weight and the pressures on its top and bottom. The air presses it down from above, and the bottom of the vessel presses it up from below. The bottom has therefore to exert an

amount of pressure equal to the weight of the liquid together with the amount of pressure exerted by the atmosphere on the top. The pressure on a square inch of the bottom will therefore be equal to the weight of the column of water which stands upon this square inch as base, together with 15 lbs., which is the amount of atmospheric pressure on the top of the column.

We thus see that the pressure of a liquid, with its surface exposed to the air, can be separated into two parts, one part being due to the weight of the liquid, and the other part being the atmospheric pressure which is transmitted through the liquid from above. In a large proportion of the cases which call for practical calculation, atmospheric pressure can be left out of account, not because it is small, but because it does not influence the result; for when pressure is uniform all round a body it does not tend to move the body one way more than another.

Fig 35.

56. The experiment represented in fig. 35 affords a good illustration of the fact that liquids press upwards as well as downwards. A lamp chimney, or any tube open at both ends, is taken, and a piece of thin card is cut rather larger than one end of the tube. It is well

water-level, is much used in surveying, when quickness is more essential than extreme accuracy. It is attached to a tripod stand which only requires to be planted firmly

Fig. 38.

on the ground, and there is no necessity for the connecting tube $b\,b$ to be exactly horizontal. As soon as the tubes are uncorked, the water will find its own level in the two upright tubes at m and n, and the observer is thus furnished with a line of sight $m\,n$, which he knows to be horizontal. Fig. 38 explains how, with the aid of this

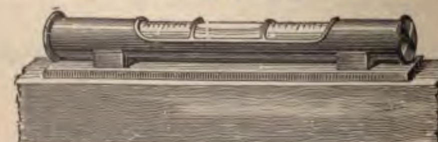


Fig. 39.

instrument, the difference of the levels of the ground at two stations A and B can be determined.

Spirit-levels, fig. 39, depend upon a different principle

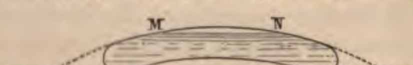


Fig. 40.

—illustrated by fig. 40—the principle that the bubble

will come to the highest part of the tube. The tube is always slightly convex upwards, and its middle point is the highest only when both ends are at the same level.

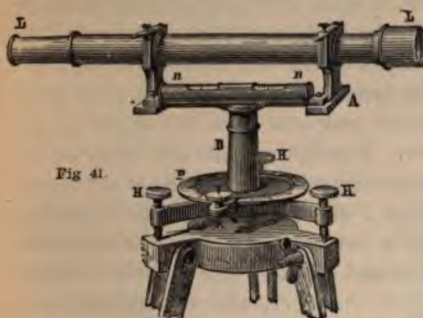


Fig 41.

Fig. 41 represents a telescope with a spirit-level attached, mounted on a tripod stand. This is the kind of instrument that is employed in surveying for railways, or other purposes requiring the determination of levels with great accuracy.

59. If we have two different liquids in tubes connected at the bottom, they will not stand at the same level unless they happen to be of the same density; but the surface of the lighter liquid will be the higher. The difference is most noticeable when the difference of density is very great, as in the case of water and mercury.

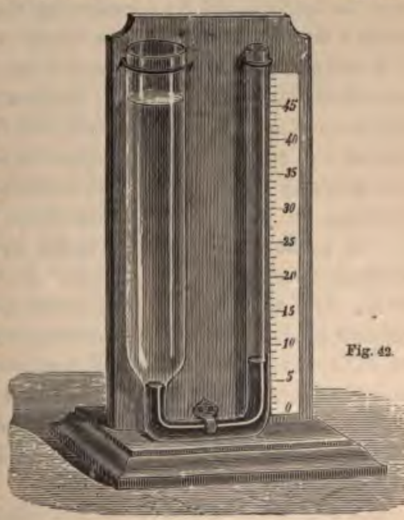


Fig. 42.

Fig. 42 shows the result of first pouring mercury into a bent tube open at both ends, and then pouring in water on the top of one of its surfaces. This surface will be depressed by the weight of the water above it, and the other surface will be forced up, but only to a very small distance compared with the depth of the water. The figure shows the lower of the two mercury surfaces standing at the height marked 5 on the scale, and the higher at 8, while the water is standing at about 47. The height of the water column is therefore 47 – 5 or 42, and the difference of levels of the two mercury surfaces is 3. The ratio of 42 to 3 is 14 to 1, and mercury is about 14 times as heavy as water. The reason may be understood by considering fig. 43, which represents a similar distribution of water and mercury. E E′ is a horizontal line drawn across from the surface of junction of the two liquids at E. The pressure at E′ must be the same as at E, because, as we travel from one of these points to the other through the mercury in the bend, the increase of pressure in going down from E to the lowest point will be exactly equal to the decrease in going up from the lowest point to E′. But the pressure at E′ is due to the column E′D of mercury, while the pressure at E is due to the column E A of water, and the pressure due to a column of liquid is jointly proportional to its height and its density. The heights E A and E′D are therefore inversely as the densities.

Fig. 43.


Fig. 44.

60. Fig. 44 represents an instrument called a *pipette*, which is intended to be partly filled with liquid by sucking

ıpper end, while the lower end, which is small, ırsed in the liquid which we wish to draw up. nough liquid has been sucked up, the mouth may ved and the top closed air-tight with the finger. trument with its contents may then be lifted and about without the liquid running out. The air ıe liquid in the instru- s at less than atmo- pressure, and though ssure increases as we own the liquid, it only ains atmospheric pres- the bottom.

'ig. 45 shows the con- n of an ordinary -pump. There is a ading from the water well to a wider part he *barrel*, in which the works up and down. s a valve at the top of e, which permits water from the tube to the but prevents it from ıg. There is also a ır in the figure a pair es) in the piston, per- the water to pass up, to pass down.

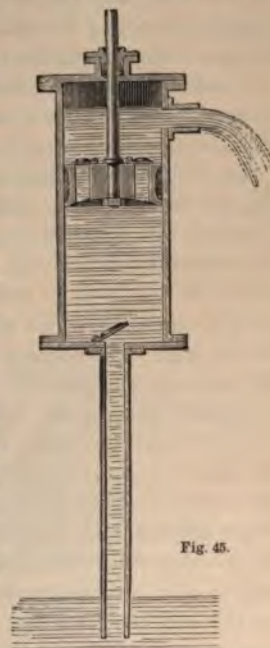


Fig. 45.

Vhen we begin to work the pump after it has been g idle for some time, the barrel and tube are full own to the level of the water in the well. As we e piston from the bottom of the barrel to the top, ınd the air beneath it, thus diminishing its pressure,

and causing the water to rise in the tube, to such a height as will keep the pressure in the lower part of the tube equal to the pressure in the water outside at the same level. The pressure at that point of the tube which is level with the surface of the water in the well, must be equal to atmospheric. In the descent of the piston, the lower valve closes, and the air which was in the barrel escapes upwards through the valves in the piston. In the next ascent of the piston the remaining air becomes still more expanded than in the first upstroke, and the water rises higher. It thus after a few preliminary strokes rises into the barrel, and the regular working of the pump begins.

In the regular working there is no air to be expanded by the ascent of the piston. The piston is completely immersed in water, and as it rises the water rises with it, the reason being that the column of water from the piston down to the well is not tall enough to balance atmospheric pressure which acts on the surface of the water in the well. The column is accordingly not only *sustained* by atmospheric pressure, but pressed by it against the bottom of the piston. If we stop pumping for a moment, so as to leave the water at rest, the pressure at any point in the tube can be calculated from knowing that it is atmospheric at the point which is level with the external water-surface, and that it decreases upwards at the rate of one atmosphere of pressure for 34 feet. Thus, at the height of 17 feet the pressure will be half an atmosphere; at the height of $8\frac{1}{2}$ feet it will be three quarters of an atmosphere, and at the height of $25\frac{1}{2}$ feet one quarter of an atmosphere. This is about as high as it would be safe to place the piston, as some margin must be left to allow for leakage.

63. When once the water has passed up through the valves in the piston, it is no longer dependent on atmo-

spheric pressure for its support, but is simply pushed up by the piston. Hence the height of the spout above the piston is not limited by any considerations of atmospheric pressure. It is sometimes as much as 50 ft., in which case the pump is called a *lift-pump*, but more usually it is only a few inches.

If the piston is leaky, it is advantageous to pour in water, and so expel air from the barrel before beginning to pump, leaks being of less consequence with water than with air, because water does not expand as air does.

64. In the force-pump there are also two valves, which are shown at A and C, fig. 50 (art. 70). One of them A opens upwards from the supply-tube into the barrel, just as in the suction-pump, and the other C opens outwards from the barrel to the discharge-pipe. A com-

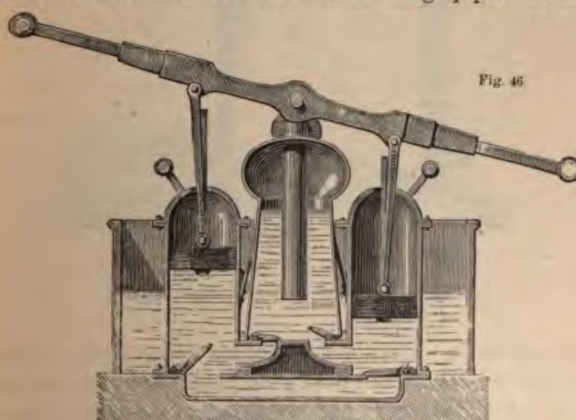


Fig. 46

bination of two force-pumps is shown in fig. 46, which is a section of a fire-engine. The left-hand piston is ascending, and water is flowing into its barrel through the valve at the bottom. The right-hand piston is descending,

and the water is being forced out from its barrel through the valve at the side into a central reservoir. From this reservoir the water rushes up the tube in its centre, which is in connection with the hose (not shown in the figure).

It will be seen in the figure that the water does not rise to the top of the central reservoir, but has an air-

Fig. 47.

space above it. The air in this space is in a state of compression, and if allowed to expand to atmospheric pressure would extend down to the lower end of the central tube. It expands a little between one stroke and the next, and is compressed again by each stroke. It thus acts the part of a spring and makes the discharge continuous.

65. The **siphon**, in its simplest form, is merely a tube with both ends bent down (fig. 47). If we put one end

into a vessel of water, and suck at the other end till the water comes over, we may leave off sucking, and the water will go on flowing of itself, provided that the discharging end is at a lower level than the surface of the water in the vessel.

Instead of sucking, we may first fill the tube by dipping it in a tub of water, and then keep the ends plugged with our fingers till we have carried it into position.

Instead of letting it discharge into the air, we may keep the discharging end in water, and the flow will continue till this water rises to the same level as that in the upper vessel.

66. The water has to run uphill in the first part of its passage through the siphon, but it then runs downhill through a greater distance, and the ultimate tendency is for the water by flowing through the siphon to find its own level.

We may substantially explain the principle of the siphon by saying that the greater weight of the taller column pulls the shorter column over, while atmospheric pressure binds the whole together.

The following explanation is more complete:—

67. Let $m\,n$, $m'\,n'$ (fig. 48) be the surfaces of the liquid in the two vessels, c the highest point of the siphon, $a\,b$ and $a'\,b'$ the parts of it which are at the levels of the two water-surfaces. Let h be the height of c above $a\,b$ and h' (a larger quantity) its height above $a'\,b'$.

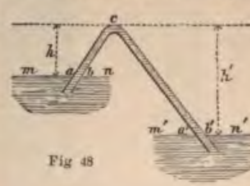


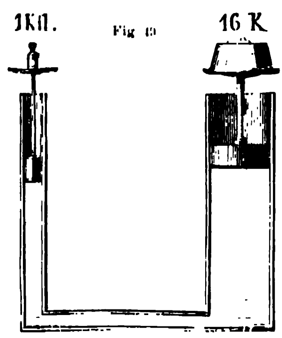
Fig 48

Suppose a plug were inserted at $a\,b$, the pressure against its under side would be atmospheric, and the pressure against its upper side would be less than atmospheric, because it is equal to the pressure at the same level in the other limb, which is less than that at the lower level $a'\,b'$.

The plug will therefore be pressed up more than it is pressed down, and hence if the plug is taken away the water will flow up. If we had supposed the plug to be at $a'b'$, there would have been atmospheric pressure below it, and more than atmospheric pressure above it. In fact, if H denotes the height of a column of water which would balance atmospheric pressure, we should have a pressure H at $a\,b$, a pressure $H - h$ at c the highest point of the siphon, and a pressure $H - h + h'$ at the top of the plug at $a'b'$. But $H - h + h'$ is greater than H by the amount $h' - h$. We can show that at whatever point of the tube the plug is placed, the difference of pressures on its two sides is $h' - h$, always tending from $a\,b$ towards $a'b'$; hence it is clear that if there is no plug, the water will be forced through the tube in this direction.

68. Principle of the Hydraulic Press.—Any additional pressure that we apply to one part of a confined liquid is transmitted to the whole. Thus if we have a liquid in equilibrium in a closed vessel fitted with a piston, and we press the piston, the pressure is increased just as much in the distant as in the near portions of the liquid. If the piston has an area of 1 square inch, and we press it with a force of 10 lbs., we produce a pressure of 10 lbs. per square inch throughout the whole of the liquid, in addition to the pressure which existed before. If the piston had an area of 2 square inches, it would need a force of 20 lbs. to produce the same effect. Hence we have an easy way to make a small force balance a

Fig. 10.



large one by means of a liquid; we have simply to make them push two pistons having areas proportional to the forces, as illustrated by fig. 49, which represents a weight balancing another 16 times as great. The large piston must have 16 times the area of the small one.

69. It is easy to show that the "principle of work" holds here, as in all other arrangements for making a less force balance a greater; for if the one piston pushes back the other, the same quantity of liquid which leaves one cylinder will enter the other, and the length which this quantity of liquid occupies will be 16 times as great in the small cylinder as in the large one—that is, the small piston must move 16 times as far as the large one. Thus the work done, as computed by multiplying force by distance, will be the same at both pistons.

Fig. 50.

70. Instead of a piston working in a cylinder which it fits, we may employ a solid cylinder of the same area, and force it into the liquid. It will displace just as much liquid as the piston, if we push it in to the same distance; and it requires exactly the same force to keep it in its place; for the pressure against the flat end is clearly the same as against the piston, and the pressures round the sides do not tend to push it either in or out. Solid cylinders employed in this manner are called *plungers*, and they are preferable to pistons when very strong pressure is required, because they can be made more water-tight. A force-pump with a plunger is shown in fig. 50.

space A C is as long as 4 or 5 inches, the little air which is in it will have expanded so much that it scarcely makes any difference in the height at which the mercury stands; then the pressure produced by the weight of the

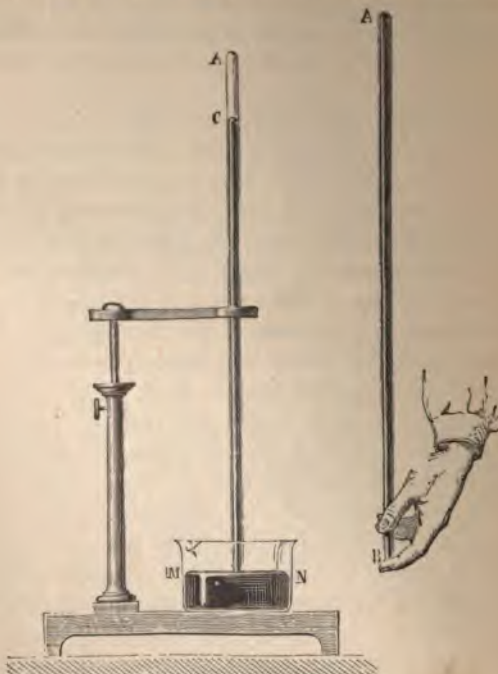


Fig. 52.—Torricellian Experiment.

column of mercury balances the pressure of the external air. The height of the column is to be measured, not from the end of the glass tube, which may be immersed to any depth, but from the surface of the mercury in the bowl; for this surface is at atmospheric pressure, and the mer-

cury inside the tube at the same level has the same pressure. If we incline the tube to one side, the summit of the column gets nearer to A, but its vertical height above the mercury in the bowl remains unchanged. This height is the same when the tube is very large as when it is only moderately large.

74. To explain how the pressure of the air is calculated, we shall suppose the area of a section of the column to be exactly a square inch. Then if the column is upright and 30 inches high, it consists of 30 cubic inches of mercury, and the weight of this column of mercury is equal to the pressure on its base. The pressure per square inch is therefore the weight of 30 cubic inches of mercury, and as a cubic inch of mercury weighs nearly half a pound, this is nearly 15 lbs.; 14·7 lbs. is rather nearer. This then is the pressure of the air per square inch when the barometer stands at 30 inches. As the height of the column changes from time to time, the pressure of the air changes in the same proportion. For instance, when the barometer stands at 29 inches, the pressure is $\frac{29}{30} \times 14{\cdot}7$, or about 14·2 lbs. per square inch.

The first person who ever measured the pressure of the air was Torricelli, a pupil of Galileo. He contrived the experiment above described of inverting a tube of mercury, which is called after him the *Torricellian experiment*, and the vacuum above the mercury is called a *Torricellian vacuum.*

75. The pressure of the air is simply due to its weight, the lower strata of air being pressed by the weight of all the strata above them. If we go to the top of a mountain, we leave a portion of the air below us, and have no longer to bear its weight. The pressure accordingly diminishes as we ascend. In ascending a mountain

a thousand feet high, the fall of the barometric column of mercury is rather more than an inch.

76. Mercury is about 13·6 times as heavy as water; hence the column of water required to balance a 30-inch column of mercury has a length of 30 in. × 13·6 = 408 in. = 34 ft. This would be the height of the column in a water-barometer, and a still lighter liquid, glycerine, is sometimes used, giving a barometric column of still greater length.

Warm mercury gives a rather longer column than cold mercury because it is lighter, and this is allowed for when accurate determinations of atmospheric pressure are required. It is agreed by general consent that the temperature at which water freezes (0° Cent. or 32° Fahr.) shall be regarded as the standard temperature for the mercury, and when the temperature is higher than this a small correction must be subtracted.

Fig. 53.—Siphon Barometer.

77. Another cause of difference arises from what is called *capillarity*. The top of the mercurial column is not flat but convex, as in fig. 52, and this circumstance (as we shall explain further on) tends to keep down the top of the column. The effect is greatest in small tubes, and is scarcely sensible when the diameter is as much as half an inch. The length of the column is always to be measured up to the highest point of the convex surface, and even this is a little below the height that we should obtain in a very large tube. A correction, equal to this difference, is added, when accurate measurement is required.

78. In some barometers, instead of a straight tube with a reservoir at the bottom, there is a curved tube, as in fig. 53, the shorter branch being open to the air.

In such instruments (called *siphon-barometers*, from their resemblance to an inverted siphon), the difference of level between the two ends of the mercurial column is to be taken as the measure of atmospheric pressure.

79. There is another kind of barometer which is now very common, called the *aneroid*. As it contains no

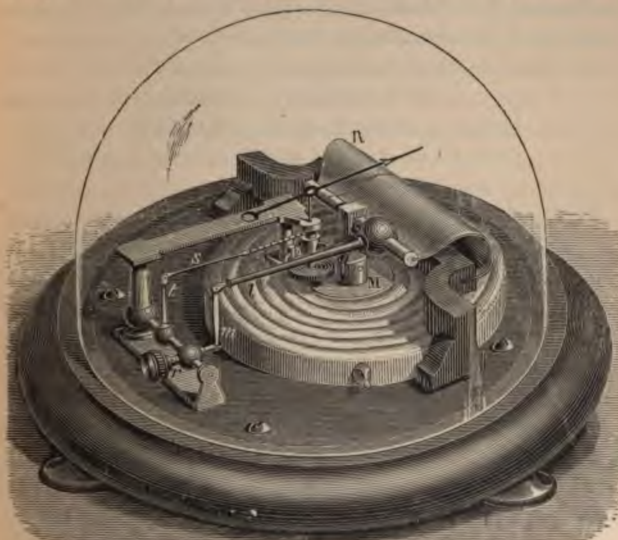


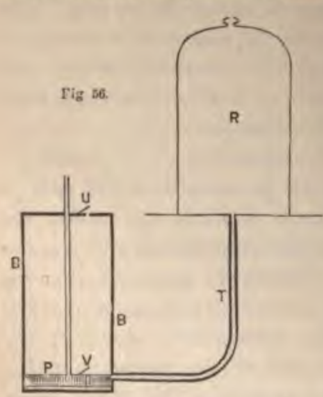
Fig. 54.—Aneroid Barometer.

liquid it is much more portable than mercurial barometers, which require great care in carrying them to avoid breakage. Our readers are doubtless familiar with its external appearance, and fig. 54 shows its construction. Its action depends on the pressure of the air upon the flexible top of an air-tight metal box, which is pushed in more or less as atmospheric pressure is stronger or weaker. The flexible top is corrugated to

enters the barrel at a small distance (equal to the thickness of the piston) from the lower end. Both valves open upwards.

In the up-stroke the piston-valve V keeps shut, and the air above the piston is pushed out of the barrel through the valve U. In the down-stroke, U is kept closed by the preponderance of atmospheric pressure outside, and the piston-valve V opens, allowing the air to pass up through it as the piston descends to the bottom of the barrel.

Fig 56.

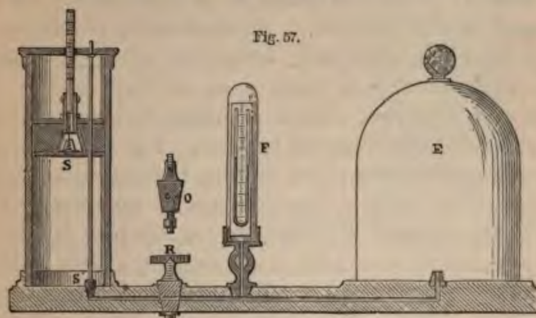


84. The valves of air-pumps are of two kinds, *silk valves* and *mechanical valves.* In silk valves, which are the kind usually employed by English makers, there is a short and narrow slit in a thin plate of brass, and a flap of oiled silk is secured at both ends to the plate in such a position that its central portion covers the slit. When the pressure of the air is greater on the further side of the plate than on the side where the silk is, the flap is slightly lifted and the air gets through; but excess of pressure in the opposite direction presses the flap down over the slit and makes it air-tight.

85. S and S′ in fig. 57 are mechanical valves. The valve S′ is carried by a rod which passes through the piston, fitting tightly enough to be lifted by the piston when the up-stroke begins; but its ascent is almost immediately arrested by a stop near the upper end of the rod, and the piston slides upon the rod during the re-

mainder of the up-stroke. The piston-valve S is all this time kept closed by a weak spiral spring. In the down-stroke the piston first carries down the valve-rod with it and closes the valve S′. It then slides upon the rod

Fig. 57.



till it reaches the bottom of the barrel, and during the latter part of this movement the piston-valve S is opened by the pressure of the air beneath it.

86. An air-pump is usually provided with two stop-cocks—one for opening and intercepting communication between the barrel and the receiver, the other for admitting the external air to the latter—a precaution without which it could not be removed from the plate on which it rests. The stop-cock R in fig. 57 (shown in section at O) does duty for both purposes, being pierced with two openings which do not communicate with each other. When the pump is working, one of these holes forms a continuation of the air-passage, as shown at R, and the other hole is idle, being open to the air at both ends. If the stop-cock is now turned through a right angle in one direction so as to take the position shown in the upper figure, the receiver is put in communication with the external air, whereas, if it is turned through a right

[illegible] consequence at first become more and [illegible]

91. [illegible] these defects consists in the fact that even [illegible] is pushed home, it is not in absolute [illegible] end of the barrel, but there is a thin [illegible]. Referring to fig. 56, when the [illegible] top of the barrel, this layer of air above [illegible] pressure, and during the down-stroke [illegible] sufficient force to keep the valve V shut [illegible] descent. The valve will not open till [illegible] the same on both sides of it, and [illegible] portion of the stroke that is [illegible] portion of the stroke thus becomes [illegible] and it may at last vanish altogether, [illegible] at all. When this point has been [illegible] in the vacuum will be obtained [illegible]. Very frequently there is also [illegible] air into the pump or into the [illegible] attainable vacuum is very differ- [illegible]. It should not exceed the pres- [illegible], and it is seldom so low as [illegible] necessary to keep the piston well [illegible] it is also necessary for the bottom [illegible] the plate very accurately, and to be [illegible] well rubbed with stiff grease. Under [illegible], and with the stop-cock turned so as to [illegible] the receiver from the barrel, the vacuum will [illegible] remain for days without sensible deterioration.

92. The basis of the calculation in art. 90 shows that the quickness of the exhaustion depends on the size of the barrel as compared with the receiver. With a given pump, the smaller the receiver is that we employ, the fewer will be the strokes required to obtain a given degree of rarefaction.

93. For obtaining very perfect vacua (a thousandth or a millionth of an atmosphere), the mercurial pump invented by Sprengel is commonly employed; its simplest form is represented in fig. 60. The length xd must be more than 30 ins. Mercury from the funnel A falls in a succession of drops down the interior of the fine tube, cd, and continually sweeps before it the air which enters this tube from the receiver R. When the process has been going on for half an hour or more, the lower portion of the tube contains a continuous column of mercury sensibly equal in height to that in a barometer, and the drops fall on the top of this column with a sharp metallic clink.

Fig. 60.—Sprengel Pump.

94. A number of very instructive experiments can be performed with the air-pump.

To show the tendency of air to expand, we may take a nearly empty air-tight bag—a bladder, or an indian-rubber ball will serve—and having secured its neck carefully so as to prevent leakage, place it under the receiver of an air-pump, as shown in the right-hand portion of fig. 61.

Fig. 61.

As we exhaust the receiver, the bag will swell out and become tight, as shown in the left-hand portion of the figure.

95. Fig. 62 represents an apparatus contrived by Otto Guericke of Magdeburg, the inventor of the air-pump, for showing the pressure of the air. The two hemispheres must fit accurately together, and must be well greased with tallow at their junction to prevent air leaking in. They are then screwed on to the air-pump and exhausted. The external air now squeezes them tightly together, and the force required to separate them can be tested by turning the tap across, unscrewing the apparatus from the pump, and attaching handles for pulling. The usual size is about 4 inches in diameter,

and requires a man's utmost strength to pull the hemispheres asunder. The following is the way to calculate the necessary force. If the diameter is 4 inches, the area of the circle will be $16 \times \cdot 7854 = 12\frac{1}{2}$ square inches nearly. As there will not be a perfect vacuum inside, we will allow for this by taking atmospheric pressure as 14 instead of 14·7 lbs. per square inch. We must multiply 14 lbs. by $12\frac{1}{2}$, and this gives 175 lbs. as the force with which one hemisphere is pressed against the other.

Fig. 62. Magdeburg Hemispheres.

It would not do to multiply 14 lbs. by the surface of the hemisphere; for the pressure everywhere acts at right angles to the surface, and we are only concerned with that component of the pressure which is parallel to the common axis of the two hemispheres. We know that a solid hemisphere would not be moved by the pressure of the air, and hence the amount of pressure against its at base must be exactly the same as the resultant of all the pressures over its convex portion.

Fig. 63.—Burst Bladder.

96. Fig. 63 represents the experiment of bursting, by means of atmospheric pressure, a piece of bladder tied over the top of a glass vessel open both at top and bottom. Thin sheet indian-rubber answers better, but requires a taller glass, as the indian-

rubber bends down a long distance before it bursts, and would touch the plate in the figure. If bladder is used, it should be the thinnest that can be procured. The bursting is accompanied by a loud report.

CHAPTER VIII.—PRINCIPLES OF FLOATATION.

97. We have now to speak of the **floating and sinking of bodies in liquids.**

If we pour water and mercury into a bottle, the mercury goes to the bottom and the water rests on the top of it, the top of the mercury or the bottom of the water forming a level surface; and any liquids that do not mix behave in the same way. If we use mercury, water, and oil, we shall thus obtain three horizontal strata, the lightest of the three liquids, namely the oil, being uppermost, and the heaviest, that is the mercury, lowest. (See fig. 64.) A solid ball of iron put into water or oil goes to the bottom, because it is heavier bulk for bulk than these liquids; but if put into mercury it floats, because iron is lighter than mercury.

Fig. 64.—Phial of the Four Elements.

98. In discussing the floating or sinking of a *hollow* ball of iron, we must compare its weight with that of

the water which it would displace if completely immersed. This volume is the same as that which would be displaced by a solid ball of the same external diameter; and if the hollow ball weighs less than a sphere of water of this size it will float; but if it weighs more it will sink. If it has exactly the same weight as the sphere of water, it will stay at any depth at which it is placed, neither tending to sink nor to rise; but we must not place it so high that any of it protrudes above the surface.

99. When a body floats on a liquid, we may divide it in imagination into two parts by supposing the plane of the liquid surface to be continued through it. The lower of these two parts displaces its own volume of the liquid, and the weight of the liquid thus displaced is equal to the weight of both parts of the floating body together. If the body is hollow, all the hollow space that lies below the surface of the liquid must be included in reckoning the volume of the lower part; for it is clear that the volume of liquid that is pushed out of the way when the body is put in, is the same as it would be for a solid body of the same external form immersed to the same depth. Similar reasoning applies to iron steamers. In every case, the weight of the steamer, including all that it carries, is equal to the weight of the water which it displaces.

100. A very instructive experiment may be performed by putting strong brine into the lower portion of a tall vessel (fig. 65) and gently filling up with water. If an egg is now gently put in, it will sink through the fresh water, because it is heavier than water; but it will not sink in the strong brine. It takes up its position at the junction of the two, and will remain suspended in the middle of the liquid for days or months. If we give it a gentle push with a stick, it vibrates up and down, and soon

comes to rest in its old position. When pushed lower than this, it comes up, because it displaces more than its own weight of the liquid· and when placed higher than

Fig. 65

this, it descends, because it displaces less than its own weight of the liquid.

101. In every case, whether a body be totally immersed or only partially immersed, it tends to go deeper when it is displacing less than its own weight, and to rise higher when it is displacing more than its own weight.

This rule applies to gases as well as to liquids, and is exemplified by balloons. The gas within a balloon is lighter than air, and if the total weight of the balloon and all that it carries is less than that of the air which it displaces, it will ascend.

A balloon at starting is usually not fully inflated. As it rises, the atmospheric pressure around it diminishes, and the gas within it accordingly expands. Suppose the balloon to be inflated to $\frac{9}{10}$ of its capacity. Then it will become fully inflated when it reaches a height at which the pressure is $\frac{9}{10}$ of the original pressure, and at which

the density is accordingly $\frac{9}{10}$ of the original density. The weight of air displaced will then be exactly the same as at starting; for the volume has been increased as 9 to 10, and the density diminished as 10 to 9. But this calculation leaves out of account the volume of the solid parts of the balloon. As these do not expand like the gas, they displace a less weight of air than at starting, and the balloon when it has attained a certain height is in equilibrium, like the egg in the vessel of brine and water. The weight of coal-gas is about $\frac{4}{7}$ of that of air.

102. When we hang a leaden plummet in water by a string, the string has not to bear the full weight of the plummet, but only the difference between the full weight and the weight of the water displaced. The weight which the string has to bear is called the *apparent weight* of the plummet, and the difference between the *apparent weight* and the real weight of the plummet is called the *loss of weight* due to immersion.

Whenever a solid body is completely immersed in a liquid, its apparent weight is less than its real weight by an amount which is equal to the weight of the liquid which it displaces.

Flint-glass is three times as heavy as water, hence a solid lump of flint-glass displaces one-third of its own weight of water, and loses one-third of its weight apparently, when immersed. Iron, being about 7 times as heavy as water, loses about one-seventh of its weight.

103. This principle furnishes a very easy method of comparing the weight of a solid with that of a liquid in which it can be immersed without injury.

If the solid weighs 7 lbs. in air and 5 lbs. in the liquid, the weight of liquid displaced is 2 lbs., and the weight of the solid is to that of the liquid, bulk for bulk, as 7 to 2.

The heaviness of a substance as compared with water

is called its **specific gravity;** thus a substance which is three times as heavy as water is said to have specific gravity 3. In the example just given, if the liquid be water, the specific gravity of the solid is found by dividing 7 by 2, and is 3·5.

104. Fig. 66 exhibits a convenient arrangement for

Fig. 66.—Specific Gravity of Solids. Fig. 67.—Specific Gravity of Liquids.

such determinations of specific gravity, the body being suspended from one of the two scale-pans of a balance, while weights are placed in the other pan, which is not shown in the figure. The body is first weighed before

and then after immersion. Instead of subtracting one of these two weights from the other, we can directly observe the loss due to immersion, by first putting sand or other suitable material into the other pan till it balances the body before immersion, and then after immersion putting weights into the pan from which the body hangs till equilibrium is restored.

105. Fig. 67 shows the application of the same apparatus to determining the specific gravities of liquids. A glass ball containing mercury is hung from the pan, and its loss of weight by immersion in the liquid under examination is observed. Its loss of weight by immersion in water is also observed. The former loss divided by the latter is the specific gravity of the liquid, for the two losses are the weights of equal volumes of the liquid in question and water.

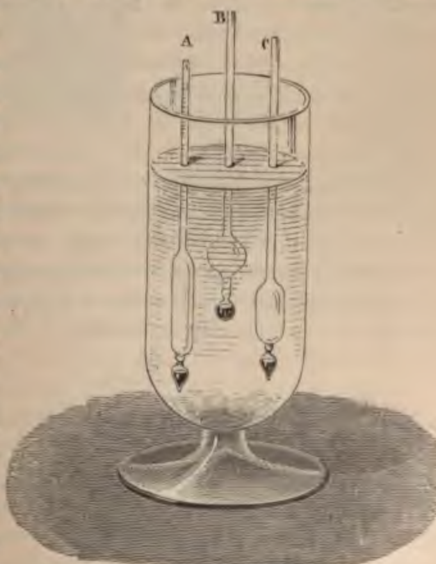


Fig. 68.—Hydrometers.

106. For rapid determinations of the specific gravity of liquids, **hydrometers** are often employed. Some forms of them are shown in fig. 68. They have a long stem,

685

which is graduated, and the lower end is weighted with mercury to keep them upright when floating in a liquid. The lighter the liquid is, the deeper does the hydrometer sink; and the observer has always to read off the division of the stem that is at the surface of the liquid. Such instruments are very much used by excise officers for determining the strength of spirits, alcohol being much lighter than water.

107. The human body consists largely of water, and has about the same average specific gravity as water. Including the cavity of the chest, which contains air, it is rather lighter than water; and a person who has sufficient skill to keep his nose and mouth uppermost, and to avoid oscillations up and down, can float without striking out. If the back of the head is allowed to come out of the water, the mouth will go under; for the difference of specific gravity is so small that only a very small portion of the body can be kept above unless aided by the muscular effort of swimming. A rather larger portion can be kept above in salt water, on account of its greater density; and this makes floating much easier. Sea water is about $2\frac{1}{2}$ per cent heavier than fresh water.

CHAPTER IX.—CAPILLARITY AND DIFFUSION.

108. We will now give some further information respecting capillarity—a subject to which we have briefly alluded in connection with the barometer. Fig. 69 shows how clean bright mercury behaves when placed in a clean wine-glass, and fig. 70 shows how it behaves when a clean glass tube is dipped into it. The mercury draws itself down at the edges, as if it were endeavouring to avoid contact with the glass as much as possible; and

within the tube, especially if the tube be small, the depression extends even as far as the centre; so that even the highest part of the liquid within the tube is lower than the general level outside.

Water, on the other hand, if the glass be not greasy, raises itself at the edges, as shown in fig. 71, and still

Fig. 69.

Fig. 70.

Fig. 71.

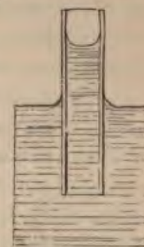


Fig. 72.

more within a small tube, as shown in fig. 72, thus manifesting a tendency to extend the surface of contact with the glass. To get the full effect, the tube should be plunged a little lower than it is intended to remain, and then drawn up again, so as to wet the surface above the level at which the liquid will stand.

Any liquid which wets glass behaves like water, and any liquid which does not wet it behaves like mercury; but the effects are different in degree for different liquids, and are especially large in the case of water.

109. The size of the tube makes a great difference. Halving the internal diameter doubles the elevation of the water and doubles the depression of the mercury; hence we can understand how liquids are able to creep up to a great height in porous substances. It is by capillarity that oil ascends in the wick of a lamp, or water in a sponge or a brick. If one corner of a towel be in the water of a basin, while the opposite corner is at

a considerably lower level outside, the towel will act like a wick and remove the water from the basin, letting it fall in drops upon the floor. A liquid will not drop from the end of a wick unless this end be at a lower level than the surface of the liquid in the reservoir.

110. The forces which produce these effects are to a great extent the same as those which produce the spherical form of drops and soap-bubbles. The surface of a liquid generally tends to contract and become as small as possible; and the surface of a given quantity of water in a drop, or air in a bubble, is least when it is spherical.

The air inclosed in a soap-bubble is at greater pressure than the air outside, as both the inner and the outer surfaces of the bubble are exerting a constant effort to contract; and for the same reason, if we partially blow a bubble, and then remove our mouth from the pipe, the bubble will draw itself into the bowl of the pipe.

A film of soapy water can easily be obtained by dipping a ring into the liquid—or by using the finger and thumb as a ring—and, whether the ring be in one plane or crooked, the film will always take such a shape as to have the smallest possible area that can span the interval.

111. In the elevation of water within a small glass tube, three actions are combined: first, the tendency of the water to increase its surface of contact with the glass; secondly, its tendency to decrease its free surface (that is, the portion of its surface not in contact with any solid or liquid); and thirdly, the weight of the liquid tending to urge it down. The first of these actions holds up the edge, and the second holds up the middle of the liquid column, in opposition to the action of gravity.

Mercury tends to decrease its surface of contact with glass, but tends still more strongly to decrease its free surface. The first of these tendencies holds down the

edge, and the second holds down the middle of the column against the force of gravity, which tends to push up the column to the same level as the liquid outside. The ratio of the two contractile forces can be determined from observing the angle which the mercury makes with the glass all round the edge, and applying the principle of the parallelogram of forces; for if the oblique pull is resolved into two components, one along the tube and the other at right angles to it, the former of these must be equal to the pull along the surface of the glass.

112. We will conclude these chapters on hydrostatics with an account of several processes which are included under the general name of **diffusion.**

If we gently pour a lighter liquid on the top of a heavier one which is of such a character as to mix easily with it, they will gradually mix of themselves, the heavier liquid diffusing itself upwards through the lighter and the lighter diffusing itself down through the heavier; but the process is so slow that it may be years before the mixture is sensibly complete.

With gases, in the same circumstances, a similar action takes place with great rapidity; so that if a bottle of the light gas hydrogen be inverted over a bottle of the heavy gas carbonic acid, with a tube connecting them, they will be completely intermixed in a few days, if not in a few hours.

It is a mistake to suppose that the carbonic acid of people's breath settles to the lower rather than the upper portion of a room. It tends to diffuse itself equally over the whole if time were given, and owing to the warmth and consequent lightness of the breath its first movement is upward. The air is better on the ground floor of a crowded hall than in the gallery.

113. Gases readily make their way through porous

substances, such as brick, or unglazed earthenware, or paper; and this process also is called *diffusion*. In this case a very exact law is found to hold, the lightest gases diffusing fastest exactly in the inverse ratio of the square roots of their densities. Thus oxygen is 16 times as dense as hydrogen, and hydrogen diffuses through porous obstacles 4 times as fast as oxygen.

Gases also escape very readily through such obstacles as the sides of an indian-rubber tube, though indian-rubber cannot be classed among porous substances. The action here is more complex, the gas being first dissolved in the indian-rubber, and then given out by it from the outside, just as the water in a sewer-trap absorbs gases from the sewer and then gives them out to the open air.

114. All kinds of salts when dissolved in water diffuse easily through porous membranes, but gum and starch diffuse with extreme slowness. Substances of the latter class are called **colloids** (from the Greek *kollé*, glue), those of the former class **crystalloids.** Colloids have hardly any taste, and do not crystallize. Crystalloids have a strong taste, and crystallize easily. Chemists often separate saline from colloid substances by placing the compound solution on one side of a membrane, (De la Rue's parchment paper is used for the purpose,) and pure water on the other side. The salts escape through the membrane, leaving the colloid substances behind. This mode of separation is called **dialysis.**

115. The entrance of water into the pores of a substance often causes an increase of bulk, and the removal of the water produces contraction again. Paper when wetted expands visibly in length and breadth, and goes into creases if its edges are fixed. Wood, when wetted, expands in breadth and thickness, but not in length, if its fibres run in the direction of the length.

A rope or thread, if it were merely a bundle of straight fibres bound together, would increase in diameter, and its length would not be much affected; but owing to its strands being wound round one another, there is a rather complicated action. The strands swell in diameter but not in length, and thus each strand having to go round a larger circumference, cannot cover so great a length as before. The rope is consequently shortened.

When a substance is first wetted and then dried, it often shrinks to less bulk than it originally occupied; and this is especially the case when the drying is performed rapidly. Shoes which have got wet through and have been dried at the fire are found to be tighter than before; but a little use stretches them again till they are as large as ever; and it is probably the case that whenever shrinking is produced by first wetting and then drying a substance, it is because the body had previously been stretched beyond its natural condition, and the wetting and drying merely takes the stretch out of it.

The shrinking of wood as it dries is very observable in buildings. The flooring boards of a new house are always laid so as to fit close, but after the house has been inhabited for a few years they leave large spaces between them. Logs of wood frequently crack as they dry, owing to the outside drying faster than the centre, and thus becoming too tight.

HEAT.

Chapter X.—TEMPERATURE AND EXPANSION.

116. When we touch a body which is warmer than ourselves we feel a sensation of warmth, and when we touch a body colder than ourselves we feel a sensation of cold.

Heat often passes from one body to another. If a hot iron is put into cold water, the iron becomes cooled and the water becomes warmed. The iron in fact gives heat to the water. On the other hand, if a cold iron is put into hot water, the iron is heated and the water is cooled, because the iron takes heat from the water.

If the iron is neither hotter nor colder than the water into which it is put, it will not be made either hotter or colder by the immersion. The iron is then said to have the same *temperature* as the water. When we say that two bodies "have the same temperature," or "are at the same temperature," we mean that putting them in contact would not cause one of them to become hotter and the other colder than at present. It is not necessary actually to put the bodies in contact to decide this point. It is sufficient to put one and the same body in contact with them both. The instrument used for this purpose is called a **thermometer.** We put it in contact with one body till it has had time to come to the temperature of that body. We then put it in contact with the other body, and observe whether the temperature indicated is the same.

When we say that one body A is at a higher temperature than another B, we mean that if they were placed in contact, A would be cooled and B warmed by the contact; or that a thermometer, after being for some time in contact with A, on being transferred to B would fall in temperature.

117. In ordinary speech we should call A warmer or hotter than B, and should call B cooler or colder than A. But here a caution is necessary. We talk of "cold" steel, and of "warm" woollen clothes; because if we touch steel and woollen cloth when both of them are at the ordinary temperature of the air, the steel feels much colder to the touch than the cloth. It gives us a stronger sensation of cold, because it takes heat from us faster than the cloth, though both are at the same temperature. On the other hand, if they are both of them at the temperature of boiling water, we can touch the cloth without taking harm, but the iron will be too hot to touch. The strength of the sensation of heat or cold that we get by touching a body depends then on some inherent property in the body, as well as on that variable property which we call its temperature. Some bodies have the power of taking in and giving out heat more readily than others, and are thus more apt both to chill and to burn us.

118. All bodies when allowed to touch, or when shut up in an inclosure that will not allow any heat to pass in or out, come at last to the same temperature.

Just as water runs down from a higher to a lower level in connected vessels, until the level is the same in them all, so heat runs down from a higher to a lower temperature in connected bodies until the temperature is the same in them all.

119. Expansion by Heat.—Heat in nearly all cases tends to produce expansion.

If we have a brass ball that will only just go through a brass ring when cold (fig. 73), we find, on heating the ball by immersion in hot water, or by holding it in the flame of the spirit lamp shown in the figure, that it is too big to go through. On the other hand, if we keep the ball cold and heat the ring, we find the ball goes through more

Fig. 73.

easily than at first. When a glass stopper sticks tight in a bottle, the best way to get it out is to warm the neck of the bottle by the friction of a piece of stout string passed round it and drawn backwards and forwards. The neck is thus made warmer than the stopper, which is consequently loosened. In laying the rails of a railway—especially in cold weather—it is necessary to leave spaces between the ends, so as to give the rails room to lengthen when the weather becomes warm.

Liquids expand as a rule much more than solids, and air and other gases expand much more than liquids. Mercury expands about 7 times as much as glass, alcohol 6 times as much as mercury, and air $3\frac{1}{2}$ times as much as alcohol.

It is the expansion of air by heat that causes the

ght up a chimney, the hot air being more expanded therefore lighter than the cold air, so that it tends to ıd.

solid bodies, the metals are the most expansible. for example, expands about half as much again as , and brass more than twice as much. It was once ımary to build long flat bars of iron into walls, for purpose of strengthening the brick- ; but it is now known that the expan- and contraction of these bars with and cold tear them away from the ar in which they are embedded, so they are a source of weakness instead rength.

0. The instrument most frequently for measuring temperature is the urial **thermometer** (fig. 74). It con- of a tube or *stem* of very small and orm bore, with an enlargement called *bulb* at one end. The mercury fills bulb and occupies a portion of the as well. The tube is divided into l parts called *degrees*, and the tempera- is expressed by stating the degree at h the mercury stands. In the ther- ıeters chiefly used in this country, the t at which the mercury stands when thermometer is immersed in a mixture e and water is marked 32°, and the t at which it stands when immersed in the steam of ng water is marked 212°. The small circle over the es is the symbol for "degrees." There is, therefore, ıterval of 180° between the two *fixed points*, as they alled, one being usually called *freezing-point* and the

Fig. 74. Thermometers.

other *boiling-point*: and if the tube is exactly uniform, these 180 degrees ought to be marked at exactly equal distances. When alcohol or any other liquid is employed instead of mercury, the degrees are marked in such a way as to make the instrument agree with a mercurial thermometer; and the actual lengths which the degrees occupy on the stem are not exactly equal, but are rather longer at the upper than at the lower end.

121. When we call the freezing-point 32° and the boiling-point 212° we are said to employ the *Fahrenheit scale*.

Another scale, which on account of its simplicity has been adopted as the standard one for scientific purposes, is called the *Centigrade scale*. It calls the freezing-point 0° and the boiling-point 100°. Hence the same length on the stem, or the same interval of temperature, which is divided into 180 Fahrenheit degrees, is only divided into 100 Centigrade degrees. These numbers are in the ratio of 9 to 5, so that an interval of 9° Fahrenheit is the same as an interval of 5° Centigrade, and a Fahrenheit degree is only $\frac{5}{9}$ of a Centigrade degree. The names Fahrenheit and Centigrade are abbreviated into Fahr. and Cent., or simply F. and C.

122. In reducing a temperature from one of these scales to the other, we have to perform two operations: one consists in multiplying by $\frac{5}{9}$ or $\frac{9}{5}$, and the other in adding or subtracting 32. Thus, if we want to find what temperature Centigrade is the same as 50° Fahr., we must first subtract 32, to find how far the temperature is from freezing-point. It is 18° above freezing-point, and since 9° Fahr. are equal to 5° Cent. we must multiply by $\frac{5}{9}$; this gives 10°. The temperature is accordingly 10° Cent.

Again, let us calculate what temperature Cent. is the

same as zero Fahr. It is 32 below freezing-point, and this 32 must be multiplied by $\frac{5}{9}$, giving $17\frac{7}{9}$; hence the temperature is *minus* $17^\circ\frac{7}{9}$ Cent., or to one place of decimals —$17^\circ{\cdot}8$ C.

Now let us take an example of the opposite kind. What temperature Fahr. is the same as 50° C.? This is 50° above freezing, and multiplying by $\frac{9}{5}$ we see that it is 90° Fahr. above freezing, that is, above 32° Fahr. It is, therefore, the temperature 122° Fahr.

123. In working numerical examples relating to conversion from one scale to the other, the student should first consider whether the question turns merely on the lengths of the degrees, and therefore merely requires multiplication by $\frac{5}{9}$ or $\frac{9}{5}$, or whether it also depends on the difference in the two starting-points.

Take, for instance, the following question. Air at the freezing-point expands by ·00366 of its volume for 1° Cent., how much does it expand for 1° Fahr.? Here we have merely to multiply by $\frac{5}{9}$; for the question amounts to this,—how much does the air expand for $\frac{5}{9}$ of a degree Cent.? and the answer will be, $\frac{5}{9}$ of ·00366, or ·00203 nearly.

Or take this question:

The temperature of London is higher in July than in January by 25° Fahr.; what is this in degrees Cent.? Here we have simply to multiply by $\frac{5}{9}$, and the answer is 14° Cent. nearly.

124. If we watch a thermometer narrowly when we first put it into warm water, we shall see that the mercury first descends for a moment to the extent of half a degree or so, before it begins to ascend. This illustrates the difference between **real** and **apparent** expansion. The mercury does not really contract, but the glass gets heated before the mercury; and as the bulb gets bigger, mercury

has to come out of the stem to fill it. If glass were just as expansible as mercury, a mercurial thermometer would not work at all, but the mercury would stand always at the same mark. The observed effect depends on the fact that mercury expands about 7 times as much as glass.

125. The best way of measuring the real expansion of a liquid is by the principle that, if two columns of liquid, one warm and the other cold, are connected at their bases by a fine horizontal tube C D (fig. 75), they will not stand at the same level, but the warmer and lighter liquid will stand highest, the heights h' C and h D being in the inverse ratio of the densities. Thus if the heights are as 55 to 56, the densities are as 56 to 55, and the expansion is such that the same quantity of liquid which occupies 55 cubic inches at the lower temperature will occupy 56 at the higher. This is about the amount by which mercury expands in passing from 0° to 100° C.

Fig. 75.

126. Air expands much more than liquids. When it is at the freezing-point, an increase of 1° C. makes it expand by 1 part in 273, and an increase of 1° Fahr. makes it expand by 1 part in 491. In raising it from freezing- to boiling-point we make it expand by 100 parts in 273, so that 273 cubic inches would become 373. Oxygen, hydrogen, nitrogen, and most other gases expand to the same extent as air.

If the air or gas is confined in a closed vessel which will not permit it to expand, the tendency to expansion is shown by an increase of pressure. For example, if we

se its temperature from freezing- to boiling-point, we rease its pressure by 100 parts in 273, so that if it s originally at atmospheric pressure its pressure will v be $1\frac{100}{273}$ of an atmosphere.

127. When a body expands, it becomes lighter, bulk bulk, than it was before, and hence warm air tends ascend through cold air, as we see in the case of fire-loons. A balloon about 3 feet high, of ordinary tissue-per, with a ring of light iron wire to hold the mouth en, can be made to ascend to a height of 20 feet or re by simply holding it over a gas flame.

128. The tendency of warm air to ascend through cold he primary cause of winds. The air over warm places continually ascending, and air from colder places comes supply its room. An ascent of this kind over the equa-ial regions is the cause of the trade-winds, which blow adily from the north-east over a belt of several degrees the northern hemisphere, and from the south-east over orresponding belt in the southern hemisphere. The son why they do not blow from due north and due ith is, that the earth is revolving on its axis, and parts re distant from the axis move faster than those which nearer. Thus the equatorial portions move the test, and air which comes to them from the two sides s not enough rotational velocity to keep up with them. e earth turns from west to east faster than this can follow it, and this makes a wind from east to st.

129. Another very regular wind is the *sea-breeze* ich blows, nearly every afternoon, at places on and ar the coast in tropical countries. It is caused by the d becoming warmer than the sea in consequence of sun's rays during the day; and a *land-breeze* in a arly opposite direction blows in the latter part of the

Of all known substances water has the greatest specific heat. Hence the specific heats of all other substances are proper fractions, that of water itself being unity.

132. Latent Heat.—Take a pound of ice in small pieces at the temperature 0° C., and put it into a pound of hot water with a temperature of 60° or 70° C. The water will fall to the temperature 0° C., and in so doing will melt most of the ice. We shall thus obtain water and a little ice, all at the temperature 0° C. The hot water has been chilled, and the cold ice has not been warmed. What has become of the heat which the hot water has lost? It has been spent in melting the ice. In order to melt ice at 0° C. and turn it into water at 0° C., we must give it as much heat as would raise 80 times its weight of cold water 1°, or would raise its own weight of water 80°.

This is expressed by saying that the latent heat of water is 80° C. The word "latent" means "hidden." When we melt the ice the heat which we give it disappears, and is in a manner hidden in the water which is produced.

A phenomenon of the same kind occurs whenever any solid substance is melted. For example, to melt lead and turn it into liquid lead at the same temperature, we must give it as much heat as would raise 5½ times its weight of water through one degree Centigrade. We therefore say that the latent heat of molten lead is 5½ C. This, it will be observed, is much less than the latent heat of water. In fact water has greater latent heat than any other liquid.

The same quantity of heat which disappears in melting reappears in solidifying, so that to turn water at 0° into ice at 0° we must make it give out to some colder body as much heat as would raise 80 times its weight of water one degree.

133. Latent Heat of Vapours.—A similar phenomenon occurs when liquid is converted into vapour. When a kettle is put on the fire, the water does not boil till its temperature has risen to 100° C. After this the water gets no hotter, and the heat which it continues to receive from the fire is expended in the formation of steam, which comes away at the same temperature 100° C. The heat expended in converting any quantity of water at the boiling temperature into steam, is as much as would raise 536 times as much cold water 1°.

When the steam is reconverted into water the heat thus absorbed reappears. If the steam given off by a boiling kettle is discharged into cold water, it heats this water much more than the same weight of boiling water would do. One pound of steam at 100° will raise 636 lbs. of cold water from 0° to 1°, whereas a pound of boiling water would only raise 100 lbs. of water from 0° to 1°. We therefore say that the latent heat of steam at 100° C. is 536.

134. It is not only during boiling that the disappearance of heat is observed in connection with the formation of vapour. Evaporation goes on at ordinary temperatures, though at a much slower rate, and evaporation always carries off heat. If we wet our hands and then allow the water to evaporate from them, our hands are cooled, and the same thing is observed if we wear wet gloves or wet shoes. It matters not whether they have been wetted with warm or with cold water, in either case the operation of drying by exposure to the air keeps their temperature low, and carries off heat from the skin.

135. Other liquids as well as water show this effect. Alcohol and ether, the latter especially, evaporate much more rapidly than water and have a stronger cooling

… spray upon any part
… constructed for the pur-
… freeze the surface.
… pain of a surgical
… straw or a small tube.
… that our breath
… will fall far below
… hoar-frost will be
…

… ether will give
… water, this
… greater, but simply
… For the same
… vapour carries off
… vapour. Water
… weight of it into
… we knew.
… of water are
… sudden
… capacity and
… a great
… supply is
… out again
… heat of
… of snow.
… of sudden

… end of a
… soon
… with
… needle, and
… But it does
… example, with a
… copper and iron are good

conductors of heat, and wood is a very bad conductor. The metals, especially gold, silver, and copper, are the best conductors known; then come stones, afterwards wood, and at the foot of the list come such substances as cloth, sheep's wool, and cotton wool, which consist of thin fibres with spaces of air between. A good conductor may be defined as a substance which offers little resistance to the passage of heat through it. Warm clothing depends for its efficacy on the great resistance which it offers to the escape of heat; it must therefore be composed of badly conducting material.

138. We have mentioned above an experiment in which good conduction is shown by making the further part of a body hot when the near end is held in the flame of a candle. This may be supplemented by an experiment in which good conduction shows itself by keeping the parts exposed to the flame cool. Let a piece of thin writing paper be tightly wrapped once round a smooth cylinder of copper, brass, or iron, an inch or more in diameter, and held in the flame of a spirit-lamp. The paper will not be burnt, nor even scorched. It is easy to understand that the same quantity of heat which would produce a very high temperature if collected in a small space will produce only a moderate elevation of temperature when it is spread by conduction through a large

Fig. 76.—Davy Lamp.

space. The *safety-lamp* used by miners and invented by Sir Humphry Davy depends upon the same principle (fig. 76). The only communication between the flame and the outer air is through wire-gauze, and a flame may play against one side of such gauze for a long time without making it hot enough to ignite combustible gas on the other side. This is very easily shown by placing a piece of wire-gauze over a gas-flame. As the gas is lowered it puts out the flame as far as it descends, and unburnt gas goes through it, so that we have a flame burning against the under side and not able to ignite the gas which is on

Fig. 77.—Action of Wire-gauze on Flame.

the upper side. The presence of this latter can be made manifest by applying a lighted match to it, when it will at once catch fire and continue to burn. Fig. 77 represents in its left-hand portion the appearance of the gauze when the unburnt gas is escaping through it above the flame, a red-hot ring being produced because the outer portion of the flame is the hottest. The second part of the figure represents the effect of turning on the gas beneath the wire-gauze and applying a light to it above. The flame will continue to burn above the gauze, but will not be able to ignite the portion of gas which is below.

139. Liquids (except melted metals, such as mercury) are very bad conductors, not better than wood. Fig. 78 represents the experiment of making water boil in the upper part of a test-tube, while ice remains unmelted at the lower end. Air and gases are also bad conductors. Hence if we want to heat a quantity of gas or liquid we should apply heat to the bottom. This will produce expansion of the lower portions, which will thus become lighter and ascend, mixing with the colder portions above them. The currents produced by applying heat to the bottom of a vessel of water are easily rendered visible by using a glass vessel and putting oak saw-dust into the water (fig. 79). The saw-dust may be allowed to settle to the bottom of the flask before applying the heat, and it will leave the bottom when heat is applied. If the lamp is placed centrally under the vessel, the saw-dust will be seen to ascend in the middle and descend at the sides. Such movements are called *convection-currents.*

Fig. 78.—Boiling of Water over Ice.

140. Radiation is another process by which heat is

transferred from hotter to colder bodies. The heat of sunshine is a good example of it. Radiant heat, like light, travels in straight lines, which we call "*rays*," and "radiant" is derived from the Latin word *radius*, which means "ray." If a screen held between us and the sun is suddenly withdrawn, we instantly feel the full heating effect of the sun's rays, whereas conduction requires a long time for heat suddenly applied to one portion of a medium to be propagated to another. Again, conduction warms the distant parts by first warming the near parts, which then act as warmers in their turn; but radiation often warms distant objects while the intervening medium remains cold. The sun's rays, for example, come through the intensely cold upper regions of the earth's atmosphere. A burning glass, used for concentrating the sun's rays on a piece of brown paper and setting it on fire, remains all the time at a very moderate temperature, and it is even possible to use a lens of ice for this purpose. We shall have more to say on the subject of radiation when we come to speak of light.

Fig. 79.—Liquid heated from below.

141. There are great differences in the radiating powers of different surfaces. Brightly polished metals are bad radiators. When hot they emit heat but slowly, and when cold and exposed to the radiation of bodies hotter than themselves they receive heat but slowly. Charcoal,

and lampblack, which is much the same thing, are exceedingly good radiators. They give out heat quickly when hot, and they absorb a large proportion of any heat that is radiated to them when they are cold. If, instead of polishing the surface of a metal, we give it a thin coating of lampblack, we make it a good radiator instead of a bad one. Good and bad radiation depend only on the surface, not on the substance beneath. Surfaces that reflect rays of light and heat well radiate badly; surfaces that are dead black, and reflect very little of any light and heat rays that fall upon them, radiate well. Black paint and black cloth, when exposed to a hot sun, become much hotter than white paint or white cloth.

142. In consequence of radiation, the surface of the ground in bright sunshine becomes much warmer than the air, and a thermometer exposed to the sun, especially if it has a blackened bulb, reads much higher than a thermometer in the shade, the latter showing only the temperature of the air.

On the other hand, on a clear starlight night, the surface of the ground emits heat rapidly by radiation to the sky, and becomes much colder than the air. On cloudy nights, as on cloudy days, there is not much difference between the temperature of the ground and that of the air.

143. Radiation, strictly so called, takes place as fast in vacuum as in air, and as fast in still air as in wind. But a hot body cools faster in air than in vacuum, and still faster in wind, owing to the conduction which takes place between the body and the layer of air in contact with it. When there is wind this layer is always cold, because it is changed so rapidly that it has not time to get warm. In vacuum there is no escape of heat by conduction at all, and thus the cooling is slower.

Chapter XII.—VAPOURS. HYGROMETRY.

144. We will now explain the *cause of dew.*

It is a common thing to see drops of water running down the inside of a window, especially if the air of the room has received a large amount of vapour from people's breath and from the burning of gas (for the hydrogen which is in ordinary gas turns into steam when it burns). These drops of water are produced in the same way as natural dew. On any summer's day, if we put very cold water into a tumbler, we shall soon see dew deposited on its outside. There is always invisible steam in the air, and some of this will be turned into liquid water by anything that is cold enough. At any particular time there is a certain degree of cold—that is, a certain lowness of temperature—that is necessary. Bodies lower than a certain temperature will collect dew upon their surfaces; bodies above this temperature will not; but, on the contrary, if there is any moisture on them it will evaporate. This temperature is called the *dew-point.* When there is much steam in the air the dew-point is high; when there is little it is low. In the daytime the surface of the ground, as well as grass and the leaves of plants, are almost always above the dew-point. On clear nights they generally fall below it; and grass falls much further below it than bare ground, because the surface of bare ground receives a supply of heat by conduction from the ground below, while very little heat can be conducted upwards through the blades of grass.

When the dew-point is below the freezing-point, the deposit consists not of little drops of water, but of little crystals of ice, and is called *hoar-frost.*

Ice evaporates when its temperature is above the dew-

point, which is generally the case in the daytime; but when its temperature is below the dew-point, as is often the case at night, instead of evaporating, it gains an addition of fresh ice on its surface from the air, the addition taking the form of crystals like the frost on window-panes.

When vapour in mid-air is cooled below its dew-point, little drops of water are deposited in the form of cloud; or, if the temperature be below the freezing-point, the cloud will consist of little particles of snow. Steam or vapour of water is clear and invisible like air. It is only when it begins to condense that it reveals its presence to the eye, by the formation of liquid or solid particles in its midst.

145. The moistness and dryness of the air have an important effect upon our health and comfort. When the dew-point is nearly as high as the temperature of the air, evaporation is checked, the perspiration accumulates on the surface of our bodies, and breathing does not refresh us as it ought to do. On the other hand, when the dew-point is very low compared with the temperature of the air, evaporation is promoted; the skin on our hands and faces gets dry and cracks, and persons with delicate lungs are liable to be attacked with cough.

146. The most generally employed instrument for observing the moistness or dryness of the air, is a pair of thermometers, of which one has no special feature, but merely shows the temperature of the air, while the other has its bulb covered with muslin, which is kept always wet by means of a cotton wick dipping in water. When evaporation is active, this one is several degrees colder than the other; when there is hardly any evaporation, it may be only a degree or a fraction of a degree below the other. Its temperature is not the dew-point, (for water

at the dew-point does not evaporate,) but is somewhere about half-way between the dew-point and the temperature of the air.

147. To give an exact idea of the effects of heat and cold upon vapour, we will describe what happens when an air-tight vessel containing nothing but water and vapour of water is heated and cooled. Such vessels are often prepared by boiling water in a glass vessel with a narrow neck, and, when the steam has had time to expel the air, sealing the neck with a blow-pipe.

In a vessel of this kind, the space not occupied by the water is always saturated with vapour. If we cool the vessel, some of the vapour condenses into water; if we warm it, some of the water goes off into vapour. Raising the temperature thus increases the quantity of vapour, and, since the space occupied by the vapour is scarcely altered, it increases the density of the vapour; it also increases the pressure of the vapour in an even more rapid ratio than the density. When the temperature is 100° C. the pressure of the vapour is one atmosphere, so that there is the same pressure inside and outside the vessel. When it is below 100° the pressure outside is the greater, and when it is above 100° the pressure inside is the greater.

At the average temperature of the air (50° F. or 10° C.) the pressure of the vapour is less than four-tenths of an inch of mercury; at the temperature of a hot bath (86° F. or 30° C.) it is about an inch and a quarter; at 100° C. it is 30 inches or one atmosphere, at 121° C. it is two atmospheres, and at 213° C. it is twenty atmospheres. These facts are very important in connection with the steam-engine. They show how largely the pressure of the steam alters with its temperature.

148. If there is only a little water in the vessel at the

beginning, and we go on warming after it is all evaporated, we obtain what is called *superheated* vapour or *non-saturated* vapour. Such vapour follows the same laws as air or any other gas; for example, if we were to allow it to expand to double its volume while keeping it at the same temperature, its pressure would be halved, and if we were to raise its temperature from 100° C. to 121° without expansion, we should increase its pressure by 21 parts in $273+21$ or 294, which is only 1 part in 14, instead of doubling it, which would be the result if it were saturated.

149. The suddenness with which vapour can be formed and condensed when there is no air present, gives rise to some very startling effects.

An instrument called the *water-hammer* is constructed by taking a large glass tube closed at one end, partly filling it with water, boiling this water, and hermetically sealing the open end (that is melting the glass together) while the steam is issuing, taking care at the same time to cease any further application of heat to the water, as the tube when closed would be in danger of bursting. When it has cooled down, it is ready to experiment with, and it contains nothing but water and vapour of water, the air having all been expelled by the boiling.

If we hold it upright, and then quickly invert it, so that the water falls from one end to the other, a sharp ring is produced, sounding like a blow of a hammer, by the water striking the lower end. This illustrates the suddenness of condensation.

150. The suddenness of evaporation is well illustrated by an experiment of Benjamin Franklin's. Take a Florence flask half filled with water, boil it over a lamp, and while boiling cork it, at the same time removing the lamp. The boiling will cease, but on completely im-

mersing the vessel in cold water, will immediately recommence with great activity. The explanation is that the cold condenses some of the vapour against the sides of the vessel, and more vapour is immediately formed to supply its place.

Instead of plunging the vessel into cold water, we may

Fig. 80.—Franklin's Experiment.

invert it, and squeeze cold water from a sponge over its top, as shown in fig. 80.

We have in this experiment (performed in either way), an example of *distillation*. In ordinary distillation, which is illustrated by fig. 81, the evaporation takes place in one vessel, which is placed over a source of heat, and condensation of the vapour formed takes place in another vessel, which usually consists of a long spiral tube im-

ıersed in cold water. In Franklin's experiment evapor-
tion and condensation both take place in the same essel.

151. Distillation is resorted to when it is desired to eparate the more volatile portion of a liquid from the

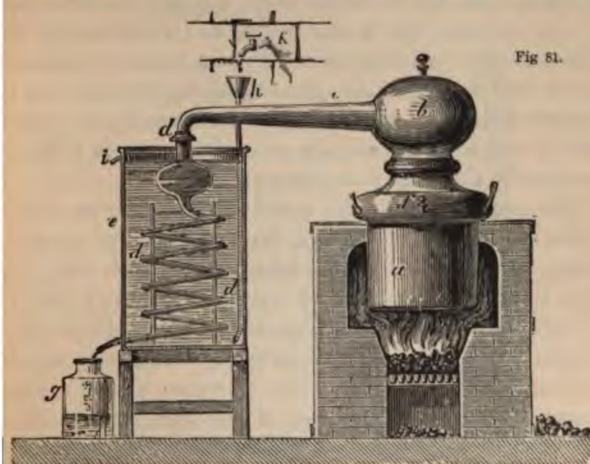


Fig 81.

ess volatile—for example, alcohol from water, or water rom brine. The more volatile portion—that is the ›ortion which is more easily evaporated—goes over first, ınd can be condensed and collected by itself. g is the essel into which it is run off from time to time, when nough of it is collected in the lower part of the *worm d*. The cold water around the worm is continually renewed hrough the funnel h, which discharges on the bottom of he vessel, while the warmer water at the top overflows hrough the pipe i.

152. Now suppose that instead of sealing our vessel when the water is boiling in it, we seal it when the

water is cold, so that the upper part will contain air similar to that outside and at the same pressure; what difference will this make in the effects above described?

In the first place, it will greatly impede the suddenness of evaporation; because the vapour that is formed on applying heat has to diffuse itself through the air before it can saturate the whole space, and diffusion of one substance through another is always a gradual operation. But it will not affect the quantity of vapour that will be formed if time be given. The same quantity of vapour that is required to saturate an empty space is required to saturate the same space when full of air.

The pressure inside the vessel was equal to an atmosphere at the time of sealing, the vessel and its contents being then cold. At any higher temperature the pressure will be greater than an atmosphere, and at 100° C. it will be about two atmospheres. If we have three vessels, one containing nothing but air, the second nothing but water and vapour of water, and the third water with air above it, and if the two which contain air were sealed under similar circumstances, then when we raise all three to the same temperature, and allow time for saturation, the pressure in the one which contains both air and water will be equal to the pressures in the other two added together.

153. Whenever vapour and dry air are mixed together in a given space, the pressure is the same as we should obtain by adding together the pressure which the vapour would exert if it had all the space to itself, and the pressure which the air would exert if it had all the space to itself.

We can now understand why steam expels the air from the upper part of a vessel in which water is boiling. Steam at the temperature of boiling exerts a pressure of

one atmosphere, and therefore a mixture of steam with even a little air, at this temperature, has a pressure of more than one atmosphere, so that such a mixture cannot remain in an open vessel.

154. The boiling-point of a liquid is the temperature at which the pressure of the saturated vapour of the liquid is equal to the pressure of the surrounding atmosphere. When atmospheric pressure changes, the boiling-point changes, so that water boils most easily when the barometer is low.

As we ascend a mountain the pressure diminishes, and the boiling-point therefore falls. 500 feet will give a fall of about 1° F., and 900 feet a fall of about 1° C.

Fig. 82.—Hypsometer.

Fig. 82 represents a portable instrument for observing boiling-points, intended to be used by travellers for measuring the heights of mountains. It has now been largely superseded by the *aneroid barometer*. A spoonful of water is poured in when the experiment is to be made; this is boiled by a lamp underneath, and the steam, after passing all round the bulb and greater part of the stem of the thermometer, escapes into the open air. The bulb does not dip in the water, as it is found that the temperature of boiling water is not so steady as the temperature of the steam which comes from it.

155. When water is to be raised to a higher temperature than its ordinary boiling-point, it must be placed in a strong vessel able to resist the pressure which the steam of the hot water will produce.

Fig. 83 represents an instrument for this purpose, called a **digester**. which is used, among other purposes,

Fig. 83.—Papin's Digester.

for boiling bones to extract the gelatine from them. It is provided with a safety-valve to prevent bursting, and the pressure at which the valve will open is regulated by the position of the weight shown in the figure. The arm on which the weight hangs is a lever, by means of which the weight presses the valve down.

The instrument was invented by a Frenchman, Denis Papin, to enable people living high up on mountains to

ook their food, and it was the earliest instance of the use f a safety-valve, the steam-engine not having then been nvented.

On the other hand, in the refining of sugar, it is necesary to evaporate the syrup by boiling, but yet it must iot be allowed to attain so high a temperature as its rdinary boiling-point. An air-pump is therefore kept onstantly at work to maintain a partial vacuum over the urface of the boiling liquid.

156. All gases are the superheated vapours of liquids, nd all or nearly all have actually been liquefied.

To liquefy a gas, it must be cooled below a certain emperature, called the *critical point* of this particular as, and must be subjected to strong pressure. The older we keep it the less will be the pressure required.

One of the easiest gases to liquefy is *carbonic acid*. Its ritical point is 31° C., and it is often liquefied in large uantities by employing a compression-pump to force it nto a strong reservoir which is surrounded with ice and vater.

Oxygen, hydrogen, and nitrogen were never liquefied ill the years 1877 and 1878. They require either an xtremely low temperature or an extremely high pressure, r both combined. In one instance a temperature of $-140°$ C. was employed, in another instance a temperaure of $-29°$ C., with a pressure of from 200 to 300 tmospheres. When the tap of a vessel containing liqueied gas is opened, the gas rushes out with great violence, nd the expansion which it undergoes cools it so much hat some of it solidifies and forms a kind of snow. This snow does not melt by exposure to the air, but it apidly evaporates. A spoonful of carbonic acid snow will take perhaps about a minute to evaporate.

157. When a plate of metal is heated many degrees

above the boiling-point of water, a drop of water placed upon it does not wet it, but runs about upon it like a drop of mercury, and glistens like a dew-drop on a leaf. It evaporates, but not near so fast as if it were boiling, and its temperature is found to be a few degrees below the boiling-point. A liquid behaving in this way is said to be in "the spheroidal state."

Chapter XIII.

CONNECTION BETWEEN HEAT AND WORK.

158. We have now to speak of the **connection between heat and work.**

Heat, by driving our steam-engines, furnishes one of our principal supplies of work; and, on the other hand, friction is a well-known source of heat. Schoolboys are familiar with the fact that a brass button rubbed upon a desk soon becomes so hot as to be painful when pressed on the back of the hand. The breaks which are applied to the wheels of a locomotive throw out showers of sparks; and the axles of railway-carriages, when not properly greased, sometimes become so hot as to set the carriages on fire. The sparks which are obtained by striking together flint and steel are due to the same cause, and copious showers of sparks are produced by the operation of grinding steel tools in cutlery workshops.

159. Heat is not a *substance*, but is one of the many forms of *energy*. There is reason to believe that it consists in some kind of to-and-fro movement of the particles of bodies; but whatever it is, we know that a certain quantity of heat is equivalent to a certain quantity of work. When work is spent in producing heat by fric-

tion, every 772 foot-pounds of work produce just as much heat as would raise the temperature of a pound of cold water by 1° Fahrenheit. Multiplying 772 by $\frac{9}{5}$ we get 1390°; hence the heat which would raise a pound of cold water through 1° Centigrade is equivalent to 1390 foot-pounds. This relation between heat and work was first accurately determined by Mr. Joule of Manchester, and the number (772 or 1390) which is used in expressing the relation is generally called *Joule's equivalent*.

160. The process of converting mechanical energy into the energy of heat is in one respect easier than the conversion of heat into mechanical energy. By employing mechanical energy to rub bodies together, we can convert the whole or nearly the whole of it into heat; but we cannot make an equally complete conversion of heat into mechanical energy. When we supply a steam-engine or a gas-engine with heat, some of this heat disappears and is converted into mechanical effect; but this is never so much as a half or even a quarter of the whole heat supplied. The rest of the heat runs through the engine and goes to waste. This waste heat comes away at a lower temperature than that at which heat was supplied to the engine; and there is no way of getting heat to drive an engine, without letting the larger part of the heat supplied come out of the engine again at a lower temperature. The excess of the quantity of heat supplied above the quantity of heat that comes away, is always equivalent to the amount of work done by the engine. If this excess is $\frac{1}{10}$ of the whole heat supplied, the engine is said to have an efficiency of $\frac{1}{10}$, and so on. There are very few steam-engines that have a higher efficiency than $\frac{1}{8}$. In order that a steam-engine may have high efficiency, its boiler must be at a high temperature, and this implies that the steam in the boiler must be at a high pressure. The

waste steam, on the other hand, should come away at as low a temperature as possible.

161. Our limits will not admit of our giving a full description of the action of the various parts of a steam-engine; but we will carefully explain one very essential point, namely, the manner in which the steam is made to push the piston to and fro and thus drive the engine.

Fig. 84 shows the piston P, which works up and down in the cylinder, and is now nearly in the middle of its up-stroke, being pushed up by steam, which enters through the lower passage $a' a'$ leading from the steam-chest B B, which is in free communication with the steam-pipe V leading from the boiler. The steam on the upper side of the piston is escaping through the upper passage $a\ a$ to the open air or to the condenser. E is the opening leading to the escape-pipe C.

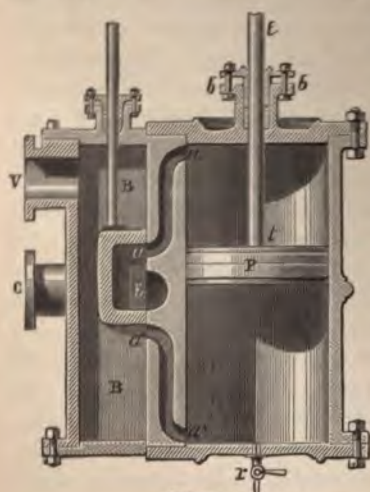


Fig. 84.

In order to push the piston down again, it is necessary to let steam from the steam-chest enter above the piston, and to let the steam below escape. The way in which this is done is exhibited in fig. 85, which represents only the parts concerned in directing the course of the steam. There is a movable piece called the *slide-valve*, which slides up and down so as to alter the connections. The

right-hand figure shows the position which we have just been considering, the steam being admitted below the piston and allowed to escape above. The second figure from the right shows the slide-valve a little lower down,

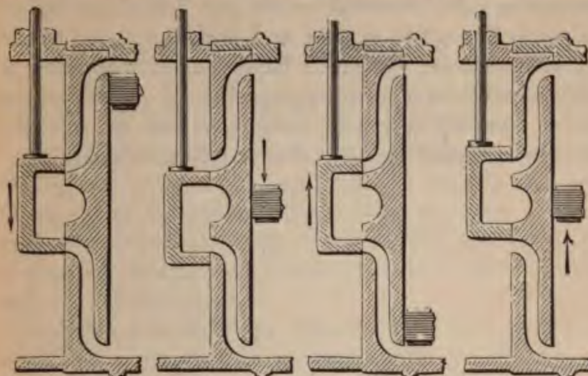


Fig. 85.

closing for the instant both passages. The third figure from the right, or second from the left, shows the slide-valve still lower; in this position the steam is admitted above the piston and escapes below. In the left-hand figure it is again for the instant closing both pas-

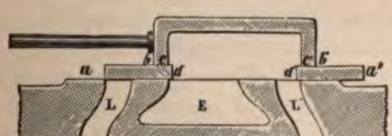


Fig. 86.

sages. The slide-valve is in constant motion up and down, being driven by a kind of crank (called an eccentric) which revolves with the fly-wheel. Very often the feet of the slide-valve are lengthened, as in fig. 86, so as

to admit the steam for a shorter time, while not sho
ing the time of escape. This is the usual plan whe
steam which comes from the boiler is at high pre
(perhaps 4 or 5 atmospheres). A little of this s
perhaps as much as would occupy $\frac{1}{3}$ or $\frac{1}{6}$ of the cyli
has power enough to expand and push the piston t
end of its stroke. A much larger quantity of wo
is obtained from a given quantity of steam, a
smaller quantity of waste heat is carried off; for
steam as it expands in the cylinder falls in temperat

LIGHT.

CHAPTER XIV.

RECTILINEAR PROPAGATION. PLANE MIRRORS.

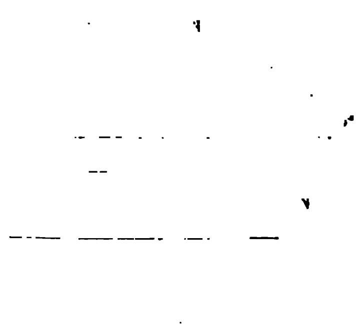
162. Light is known to us through our sense of sight. The things which we see send light to our eyes, and it is by means of the light so sent that we see them.

Some bodies allow light to come through them, and are called *transparent;* others prevent it from passing, and are called *opaque.*

An opaque body hides from us any object which lies upon the production of a straight line drawn from our eye to the opaque body. On the other hand, when we see an object through a hole in an opaque obstacle, the object so seen lies upon the production of a straight line drawn from our eye to the hole. It is thus proved that light travels in straight lines. A line along which light travels is called a *ray*, and the name is also applied in a loose sense to the light which travels along the line. As a line has no breadth, every point of a visible object must be regarded as sending out an infinite number of rays in different directions. When we want to speak of all the rays which a point of an object sends to the pupil of an observer's eye, or to the object-glass of a telescope, or to any other surface of finite size, we call them a *pencil* of rays. They form a solid cone or pyramid from whose vertex they all proceed.

163. The fact that light travels in straight lines is conspicuously shown by a beam of sunshine coming

188. Reflection.—When a ray of light, as S I, fig. 90, [illegible] plane mirror at I, it is reflected in the direction [illegible] making the same angle with the mirror as the ori[illegible] [illegible] line I N at right angles to [illegible] called the normal, and the three lines [illegible] the plane which is at right angles [illegible] plane of the mirror. I is the point of incidence. S I the incident ray. I O the reflected ray. S I N the angle of incidence. N I O the angle of reflection. The angle of incidence and the angle of reflection lie in the same plane and are equal. Let S be a small object from which the incident ray proceeds, and [illegible] distance on the other side of [illegible] the line S S' which joins [illegible] mirror. Then if we pro[illegible] backwards it will pass through S'. [illegible] other point of incidence [illegible] come from S, as we [illegible] will come as if from S' [illegible] backwards they would pass through S'. This is the reason why the mirror shows an image at S' of the object at S.



189. In fig. 91 A B is a real arrow in front of the mirror, A' B' is its image behind the mirror. O is the pupil of an observer's eye, and the figure shows two pencils of rays which enter this pupil. One pencil seems to come from A' and the other from B', whereas they

really come from A and B and undergo reflection at the mirror as shown in the figure. The dotted cone A′Q is exactly like AQ the cone of incident rays. The reflected rays form a frustum of a cone QO, and the dotted cone fits this frustum so as to make a complete cone A′O, with A′ as vertex. Similar remarks apply to the cone B′O

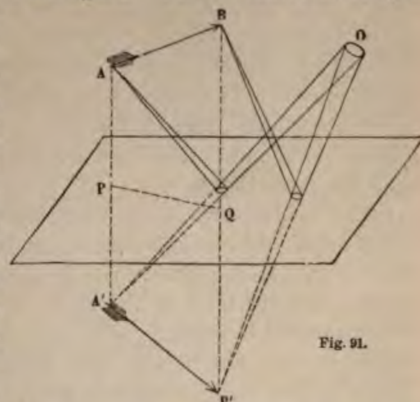


Fig. 91.

The middle point P of the line AA′ lies in the mirror, and so does Q the middle point of BB′.

Fig. 92.—Image of a Candle.

The image A′B′ is of the same size as the object AB, and though the figure only shows the rays from the ex-

treme points, a similar coustruction is applicable to all other points. The whole image $A' B'$ is made up of the images of the different points of the object $A B$.

Fig. 92 shows a candle in front of a mirror, the image of the candle behind the mirror, and an observer looking at the image. The course of a pencil of rays from the tip of the candle-flame to his eye is shown by the continuous lines, and dotted lines are used in the same sense as in the preceding figure.

Fig. 93 illustrates in a very beautiful manner the reflection of objects in a landscape from the surface of still water. Each point of the image appears to be just as far below the level of the water as the same point in the real object is above.

170. It must not be supposed that all the light which falls on a reflecting surface is reflected. The reflected light is less in amount than the incident light, so that the image is less bright than the object. If the reflecting surface is metallic, the amount of light reflected is nearly the same at all angles of incidence; but in the case of reflection from the surface of a transparent substance such as glass or water, the amount is very different at different angles, being greatest when the incident rays make a very acute angle with the surface, and least of all when they are at right angles to it. Water does not reflect so much light as glass, and glass does not reflect so much as diamond. The brilliancy of jewels is due to the large quantity of light which they reflect.

In ordinary looking-glasses the reflection is given by a metallic surface, composed of mercury and tin, at the back of the glass plate; the glass merely serves to protect this surface from becoming tarnished by exposure to the air. A little light is reflected at the front of the glass, but in ordinary circumstances not enough to be

Fig. 93.

Two of the images are formed by light which has been once reflected, two by light which has been twice reflected, and one by light which has been three times reflected. If the mirrors were placed at 30° we should have twelve images instead of six; and when the mirrors are parallel, as in fig. 96, there is no limit to their number except the

Fig. 97.—Kaleidoscopic Pattern.

limit imposed by loss of light in successive reflections. O is the real object, and the first six images are shown. The pencils of rays traced in the figure are intended to explain how the third images a_3 o_3 are formed by light which has been three times reflected.

By employing three mirrors, and placing them so as to inclose an equilateral triangle, we obtain the effect shown in fig. 97, where the central triangle contains the real object and all the rest of the pattern is made up of images.

173. The well-known and beautiful optical toy called the **kaleidoscope** (invented by an eminent scientific man, Sir David Brewster) is constructed on these principles. It contains two or sometimes three plates of glass set at 60°, or some other angle that gives a symmetrical pattern. The observer looks in at one end between the plates, and at the other end there are loose pieces of coloured glass, which constitute the object of which images are to be formed. As the rays which come to the observer's eye have been reflected at a very acute angle, the surface of the glass reflects a large proportion of the incident light. The back of the glass is not silvered, but is blackened to prevent reflection; for reflection from front and back at once would produce confusion.

Chapter XV.—CONCAVE AND CONVEX MIRRORS.

174. Concave Mirror.—For many purposes in optics concave mirrors are employed. Sometimes their form is parabolic, but more usually it is spherical, that is to say, it is a portion of the surface of a sphere. When parallel rays fall upon a parabolic mirror properly placed, they are all reflected to one point called the *focus;* and conversely, if a source of light be placed at the focus, the rays which it sends to the mirror will be reflected as a parallel beam. Parabolic mirrors are often employed in connection with the electric light, when it is desired to throw a strong light upon some distant object.

175. The direction of the reflected ray at any point of a concave or convex mirror is determined by the same law which we have already stated at the beginning of art. 168 for a plane mirror. Draw the normal (that is, the perpendicular) to the mirror at the point of inci-

dence. Then the reflected ray, the incident ray, and the normal all lie in one plane, and the incident and reflected rays make equal angles with the normal. The curve called the parabola possesses the property that the normal at any point makes equal angles with a line drawn to the focus and a line drawn parallel to the axis.

176. When parallel rays fall upon a spherical concave mirror, as in fig. 98, they are not accurately reflected to one point, but those from the outer parts cut the axis nearer to the mirror than those from the central parts.

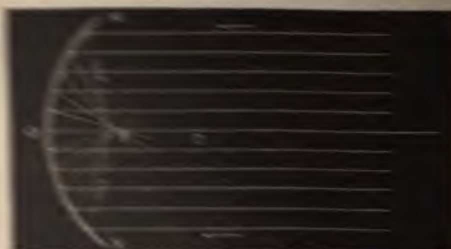


Fig. 98.

The mirror in the figure has an aperture of about 96°, that is to say, the arc MON is an arc of about 96°. This arc is divided into twelve nearly equal parts, each of which is therefore about 8°. The rays reflected from the points 8° and 16° on each side of the vertex O meet the axis almost exactly at the point F (called the *principal focus*), which is just midway between the vertex O and the centre of the sphere C (called the *centre of curvature* of the mirror). The aperture of a spherical mirror ought not to exceed 20° or 30° if we want it to reflect rays accurately to a focus, but a parabolic mirror may have as large an aperture as we like to give it.

177. Let us suppose that the aperture of our spherical

concave mirror is not too great. Then rays coming to the mirror from a very distant point may be regarded as parallel, and will be reflected to meet in a point midway between the centre of curvature and the mirror. If we draw a line from the distant point to the centre of curvature, and produce it to meet the mirror, the image will be upon this line, at that point of it which is midway

Fig. 99.

between the centre of curvature and the mirror. By applying this construction to the different points of a distant object, we see that the image will subtend the same angle at the centre of curvature as the object. The sun subtends an angle of about half a degree; hence the image of the sun subtends an angle of half a degree at the centre of curvature. If we describe a circle with a radius equal to half the radius of curvature, an arc of half a degree on this circle will be equal to the diameter of the sun's

image. As all the sun's rays reflected from the mirror pass through the image, there is a great concentration of radiant heat and light in this small area, and a piece of brown paper held in it may be set on fire. With very large mirrors, some of the most refractory bodies in nature have been melted.

178. When the object from which the rays proceed is at only a moderate distance—in fact, any distance ex-

Fig. 100.

ceeding half the radius of curvature—an image is still formed in front of the mirror. Two cases are exhibited in figs. 99 and 100. In both figures the object is a lighted candle, and the image is thrown by the mirror upon a screen. If we want the image to be visible on both sides of the screen, as in the first figure, the screen must be translucent, and may be of white porcelain or white tissue-paper. If we only want it to be visible from the side next the mirror, white card or thick white paper is better. The image is always inverted, and if lines were drawn joining each point to its own image, these lines would all pass through the centre of curvature.

In the first figure the image is diminished, in the second it is magnified. The image is always diminished when it is nearer to the mirror than the object is, and magnified when it is more remote than the object. When both are at the same distance, there is neither magnification nor diminution; the distance in this case is equal to the radius of curvature. The two distances are always interchangeable;—if the image of a point A is formed at

Fig. 101.

a point B, then the image of the point B will be formed at the point A. When the distances are interchanged, the relative sizes are interchanged too; so that if the image was half as large as the object before the change, it will be twice as large as the object after the change.

179. It is not necessary to employ a screen to show an image, unless we want to show it to several people at once. It can be seen in mid-air by an observer who places himself in a line with the image and mirror. In fig. 101 the object is an inverted bouquet B, within a box, which is open on the side next the mirror, and is at a distance

equal to the radius of curvature. The observer sees, as it were, an erect bouquet on the top of the box. To aid the illusion, a real jar is placed on the box, and the phantom bouquet appears to stand in it.

180. A complete change takes place in the phenomena

Fig. 102.—Virtual Image in Concave Mirror.

when the object is brought nearer to the mirror than half the radius of curvature. The image then appears behind the mirror, as in the case of a common looking-glass, but magnified, and at a greater distance behind (see fig. 102). As the object is moved nearer to the mirror the magnification becomes less.

181. Convex Mirrors.—A convex mirror gives diminished images. The image is always behind the mirror, but not so far behind as the object is in front;—in fact, it is never further behind than half the radius of curvature, this being its distance when the object is at a very great distance in front.

182. When a given beam of incident light falls upon a mirror, we can alter the direction of the reflected beam by turning the mirror about; and when we turn the normal nearer to or further from the incident ray, we turn the reflected ray twice as much. If we want a ray to be reflected back upon itself, we must make the normal coincide with it; if we want it to be reflected at right angles, we must make the angle between it and the normal 45°.

CHAPTER XVI.—REFRACTION.

183. Refraction.—When we look at objects in an aquarium, or in any vessel with plane glass sides containing a clear liquid, we see curious displacements of the objects from their true positions. Similar displacements may be noticed whenever we look through the surface of water at objects beneath. They are due to the fact that a ray of light passing out of a liquid into the air is bent at an angle. The ray in the liquid is straight, and the ray in air is straight, but these two straight lines make an angle with each other. There is only one case in which they are in the same straight line, and that is when the incident ray coincides with the normal. The further the incident ray is from the normal, the greater the amount of bending will be.

Bending occurs in like manner when a ray passes out of air into a liquid; and the same two lines which repre-

The ratio of A F to A D, which is $\frac{4}{3}$ for water, is different for other liquids; whatever its value may be, it is called the *index of refraction* for the liquid in question.

186. The same law holds when, instead of a liquid, we have a transparent solid, like glass. The index of refraction for glass is $\frac{3}{2}$ or more, and increases with the density of the glass. As $\frac{3}{2}$ is greater than $\frac{4}{3}$, there is more bending when a ray passes from air to glass than when it

Fig. 105.—Refraction and Total Reflection.

passes from air to water, the angle of incidence being supposed the same in the two cases.

187. Critical Angle. Total Reflection.—Fig. 105 represents a number of rays refracted out of water into air. They all come from a point O in the water. One of them is incident normally on the surface, and emerges normally, thus keeping its course straight. Six rays on the right and six on the left of this are bent, the bending

being greater as we get further from the normal; and three rays on each side beyond these illustrate a fact which we have not yet mentioned. They are too far from the normal to be refracted into air at all; and what happens is—they are reflected back into the water, as shown in the figure, the surface of the water behaving, as far as they are concerned, like a highly polished mirror. The reflection in these circumstances is more complete

Fig. 106.

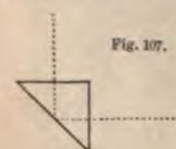
than we can obtain in any other way, sensibly the whole of the incident light being reflected; hence it is called *total reflection*, or *total internal reflection*.

There is a certain limiting angle such that, if a ray in water makes a smaller angle than this with the normal, it will be refracted into the air; but if it makes a larger angle, it will undergo total reflection. This limiting angle is called the *critical angle*, or *the critical angle of total*

reflection, for water. We can find it by making A D in the construction of fig. 104 coincide with A N, so that we shall have a right-angled triangle in which the side A N is 3, and the hypotenuse A E is 4; the angle A E N will then be the critical angle for water. To find the critical angle for glass, A N must be 2 and A E not less than 3. A ray incident at 45° will emerge from water, but will be totally reflected in glass.

188. Fig. 106 shows the position in which the eye of the observer should be placed to see total reflection at the surface of water. The eye and the object to be reflected must both be below the level of the surface. The object may either be in the water, (a spoon answers very well,) or may be outside as in the figure. The water should be perfectly still, and it is therefore better to rest the vessel on a stand. Total reflection in glass is best shown by means of a prism having the shape of a right-angled isosceles triangle (fig. 107). A ray incident normally at one of the two sides is totally reflected at the hypotenuse, and emerges at the other side. Thus objects opposite one of these sides are seen by an observer looking in at the other, and appear 90° away from their true position.

Fig. 107.



189. Displacement of Objects by Refraction.—If R (fig. 103), is the position of an object under water, and R I S the course of a ray from it to the observer's eye, the observer will see it in the direction of S I produced, shown by the dotted line in the figure. The point in this line at which it will appear to be, if the observer is looking with both eyes in the ordinary way, is exactly over its true position at R, that is, at the point where a line drawn vertically upwards from R meets the dotted

ɜ. Objects under water, when we look at them ough the surface of the water, always appear lifted Hence if a straight stick is held in a sloping posi-ı, half in air and half in water, it appears bent. The ing up is least when we look straight down into the ter; the objects then appearing at three-fourths of ir true distances from the surface, so that if the water really 4 feet deep it will appear only 3 feet deep. ıen we look in a sloping direction, the displacement is ater, and increases till the direction of vision is so ırly horizontal that the light reflected from the surface vents our seeing what is beneath.

190. The following experiment is well known and y instructive. Put a coin at the bottom of a basin,

Fig. 108.—Vision through Plate.

ire from it till the coin is just hidden from your view the edge of the basin, and then get some one to pour ter into the basin till it is nearly full. This will der the coin visible to you, by as it were lifting up bottom of the basin.

191. When a ray passes through a piece of plate-glass, a vessel of water with parallel sides, it forms a zigzag, last part being parallel to the first, as shown in fig. 3, which represents the course of a pencil of rays from point S through a glass plate to an observer's eye.

The image will be at S′, which is nearer to the plate than S.

By a combination of refraction and reflection, a number of images of a bright object may be seen in a piece of plate-glass (fig. 109), whether silvered at the back or not. A gas flame turned very low, or the bright end of a gold pencil-case, will answer for the object, and the incidence of the light should be very oblique. The nearest image is formed by reflection from the front of the glass; the second is seen by light that has been first refracted into the glass, then reflected at the back, and then refracted out of the glass again. (This is the way the ordinary image in a looking-glass is formed.) The third image is formed by light that has been twice reflected from the back, besides being once reflected at the front and twice refracted; and the succeeding images are similarly explained. Fig. 110 shows the history of an incident ray from an object at S. When it strikes the surface, part of it is reflected and another part enters the glass. This latter part strikes the back and is in part reflected there. On again arriving at the front, it is partly refracted into the air and partly reflected into the glass, and so on for several successive reflections and refractions, becoming at last so much reduced in quantity as to be

Fig. 109.—Images of Candle in Looking-glass.

nsible. The six portions which are represented as rging in front give rise to the six images $S' S^{\circ} S_1 S_2 S_3$, The dotted lines are to show that the actual rays roduced backwards pass through these images.

92. When a ray passes through a medium whose sity is not uniform, but changes gradually from point oint, the ray is bent; but instead of being bent at an

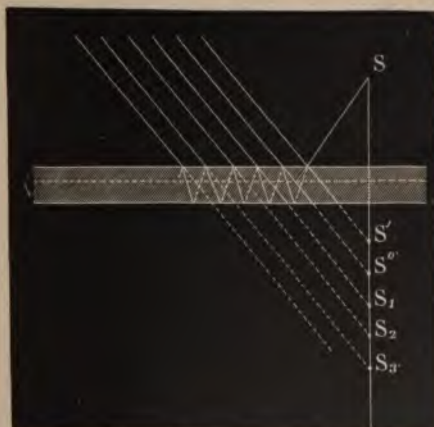


Fig. 110.—Multiple Images in Plate.

le, it is bent into a curve, and it always follows the of bending towards the side on which the index of action is greatest; that is, in most cases, the side on ch the density is greatest. The cheaper kinds of s abound in irregularities of density, which cause iceable distortion of objects seen through them; and qualities of density in air produce the flickering aprance that is seen near hot stove-pipes and over the s of gas flames.

93. A gradual bending takes place in the rays which

pass through the earth's atmosphere on their way from heavenly bodies to the earth's surface. The lower layers of air are denser than the upper, and consequently rays are bent continually downwards. Let E A, fig. 111, be such a curved ray coming from a star E to the eye of an observer at A. (The height of the atmosphere in comparison with the size of the earth is greatly exaggerated to make the figure plainer.) Then the direction in which

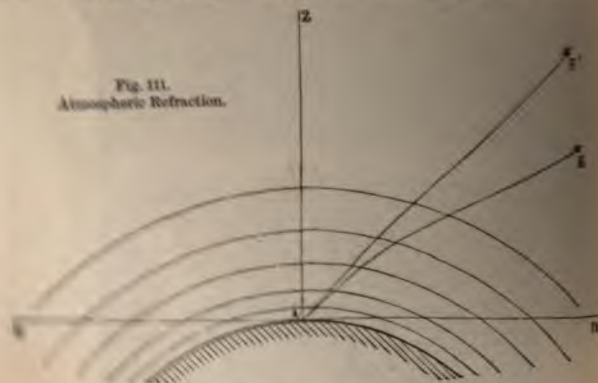


Fig. 111.
Atmospheric Refraction.

the star is seen will be that of a tangent A E′ drawn to the curve at A. The stars are thus lifted up by refraction, and the stars which are most lifted up are those which are nearest to the horizon. The effect is nearly the same as if we suppose the atmosphere to be made up of a finite number of layers bounded by the circular arcs in the figure, and the ray to keep a straight course within each layer, but to be bent at an angle in passing from each layer to the next.

124. Prism.—It is easy to produce large changes in the direction of rays of light by employing a *prism*. All that is really necessary is a piece of glass with two plane

faces inclined at a considerable angle to each other; but the prisms commonly employed are triangular (either equilateral or isosceles,) as in fig. 112, which shows a prism mounted on an adjustable stand, by means of which it can be raised, lowered, and turned about into any position that may be required. When it is placed (as in the figure)

Fig. 112.—Vision through a Prism.

with one of its faces (which we shall call the *base*) horizontal, and one of its three edges at the top, a ray entering at one of the two sloping faces, then traversing the prism to the other sloping face, and there emerging, will be bent down, as shown by the dotted line from the candle to the observer's eye in the figure, and the observer will consequently see the candle lifted up, for it will appear to him to be in the prolongation of the ray which enters his eye.

195. To understand how this is, look at fig. 113, where S I is the incident ray, N I the normal at the point of incidence, I E the course of the ray through the prism, E B the emergent ray, and E N′ the normal at the point of emergence. The angle which the ray in the prism makes with the first normal is smaller than the angle of incidence N I S, and the angle which it makes with the second normal is smaller than the angle of emergence N′ E B; for the rule always is that the ray in glass makes a smaller angle with the normal than the ray in air. At both faces it is thus bent towards the base of the prism, or away from the angle in which the two faces meet, which is often called for shortness *the angle of the prism*, or *the refracting angle.*

Fig. 113.—Refraction through Prism.

196. By altering the direction of the incident ray we shall alter the direction of the emergent ray. For instance, if we make S I steeper, E B will be less steep; the bending at I will thus be increased, and the bending at E diminished. The total amount of bending will not be exactly the same as before. The total amount of bending is least when the bending at I is equal to that at E, in which case the ray I E is parallel to the base of the prism (supposed isosceles or equilateral), and the incident ray makes the same angle with the first face that the emergent ray makes with the last. The further we depart from this symmetrical position, the greater is the

deviation (*i.e.* total bending) that we obtain. The symmetrical position is accordingly often referred to as the *position of minimum deviation;* and it is more used than any other position, because in most of the applications of prisms it gives clearer images than any other position.

197. The large amount of bending that a prism gives brings into prominence a circumstance which may easily escape observation in experiments on refraction at a single surface of water or through a glass plate;—the circumstance that blue light is more bent than red light, and that such an object as a strip of white paper on a dark ground, or a gas or candle flame, when seen through a prism, is coloured at the edges, the edge furthest away from the real object being blue, and the near edge red or orange. The index of refraction of a substance is accordingly different for the different colours which combine to make up ordinary light. We shall return to this subject later.

198. When the angle of a prism is small—say anything between 0° and 15°—and the angles of incidence and emergence are not very unequal, we may apply the approximate law of refraction given for small angles of incidence in art. 184, and say that the angle of incidence is μ times the angle of refraction at the first surface; the Greek letter μ (pronounced *mu*) being used as a symbol to denote the index of refraction; and in like manner, that the angle of emergence is μ times the angle which the ray in the prism makes with the second normal. Hence it can be shown by elementary geometry that the bending at the first refraction is $\mu - 1$ times the first angle of refraction, and that the whole bending is $\mu - 1$ times the angle of the prism. Thus if the angle of the prism be 10°, and the index of refraction $\frac{3}{2}$, the ray will be

cipal focus on the other side of the lens, since rays may pass through the lens in either direction.

Fig. 116.—Parallel Rays made to Converge.

202. Fig. 117 shows what happens when rays parallel to the axis fall upon a concave lens. They diverge; and if the lens does its duty perfectly they diverge from one point; that is to say, the emergent rays, if produced backwards, would meet in one point F, which is still called

Fig. 117.—Parallel Rays made to Diverge.

the *principal focus*, but it is only a *virtual* focus, because the rays themselves do not pass through it, but only their backward productions.

203. When we regard a concave lens as made up of prisms, the bases of the prisms must be turned away from the axis, whereas in a convex lens they are turned towards

e axis. Prisms bend rays towards their base; hence ncave lenses bend rays *from* the axis and convex lenses nd rays *towards* the axis. In other words, concave nses tend to make rays diverge, and convex lenses tend make them converge.

204. The properties of a convex lens are similar to ose of a concave mirror, and the properties of a conve lens to those of a convex mirror.

When we look through a concave lens, it makes objects pear smaller and nearer; and this is the case whatever eir distances are.

When we look through a convex lens at an object tween the lens and the principal focus, it appears larger id further off than it really is; but when we place the ject further off than the principal focus, there is a comete change in the phenomena. In this case, if our eye is ar the lens, the object appears magnified, but very con-

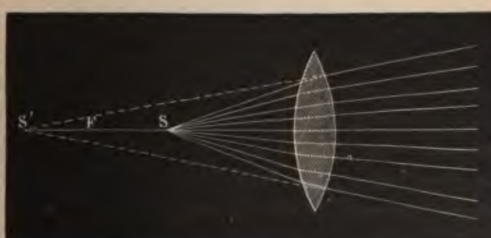


Fig. 118.—Rays made less Divergent.

ised; if, however, we draw back a sufficient distance, we ay be able to see an inverted image of the object apearing to be between our eye and the lens. In order to see is, it is necessary that the eye be removed back beyond ie principal focus,—a foot or two feet further will be ifficient if the object is distant; or we may throw the

inverted image on a screen, and thus show it to several people at once.

205. Fig. 118 illustrates the action of a convex lens when the object is nearer than the principal focus. The rays from any point of the object, as S, are made to diverge from a more distant point S′. To a person looking through the lens from the other side, S will seem to be at S′. Thus the point S′ is the image of S, and each point of the object has in like manner its own image.

Fig. 119 illustrates the case where the object is beyond the principal focus. The rays from a point S of the

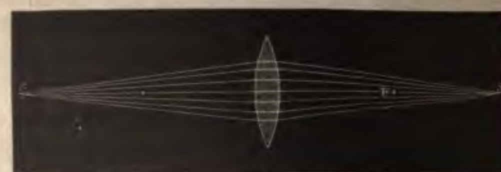


Fig. 119.—Divergent Rays made Convergent.

object are now made to converge to a point S′ on the other side. If there is a small candle-flame at S, all the light that it sends through the lens will be concentrated at S′, and a bright spot will accordingly be thrown upon a screen held there.

206. There is a very simple rule connecting the size of an image with its distance from the lens. It is illustrated by fig. 120, where the small arrow A B is the object, and the large arrow is its image, as seen by a person looking through from the other side. If we draw a straight line through any point of the object and the corresponding point of the image, this line must pass through O, the centre of the lens; so that the line O A must pass through one end of the image and the line O B through the other end. It follows that the lengths of the object and the

nage will be directly as their distances from O. Thus if ıe image is three times as far from the lens as the object , it will be three times as long and three times as broad.

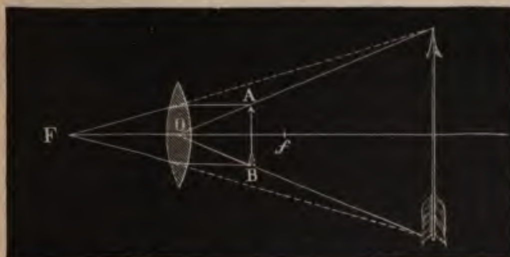


Fig. 120.—Magnification of near Object.

Fig. 121 illustrates the same thing for a concave lens. Iere the large arrow A B is the object, and the small rrow *a b* the image. We see that, if the image is only alf as far from O as the object is, it will be only half as ng and half as broad. When an image is thrown by a

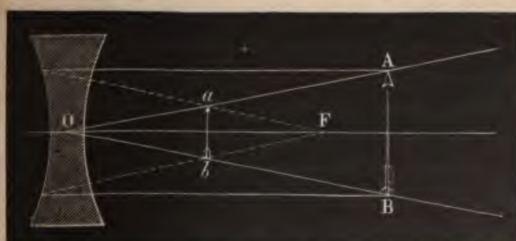


Fig. 121.—Diminution.

›nvex lens upon a screen, the same rule holds;—the linear imensions of an object and its image are in the same atio as the distances of the object and the image from he lens.

207. An image that can be thrown upon a screen can

&c., all in their natural colours; and if the sun is shining brightly, so as to make the picture sufficiently luminous, the spectacle is very striking.

These pictures are formed by a very large convex lens, which is straight over the centre of the table, at a height equal to or a little greater than its own focal length, which is several feet. Above the lens is a plane mirror rather larger than the lens, and at a slope of about 45°, which can be turned round a vertical axis so as to face towards any point of the compass at pleasure. If we could look up into the mirror, we should see an image of the landscape straight overhead; and the lens throws on the tablecloth an image of this image.

212. In the photographic camera, no mirror is employed; but the lens directly faces the object to be represented, and throws an image of it on the sensitized plate. Before putting in the plate, the operator throws the image on a screen of ground glass, and looks at it from behind. When he has adjusted it to his satisfaction, he shuts off the light, substitutes the sensitized plate for the ground glass, and then readmits the light for the proper time. The explanation of the chemical processes by which the picture is first developed, and then rendered permanent, does not fall within our province. We will merely call attention to the fact that light is capable of producing chemical effects.

213. The **magic lantern** is another example of the same property of convex lenses. A small picture, painted in transparent colours on a glass slide, is placed behind the lens, at a distance a little greater than the focal length. A greatly magnified image is formed at a much greater distance in front, and is thrown upon a white wall or a white sheet. The apartment is darkened, and the light which forms the image comes from a flame in the centre

of the lantern. A second convex lens is placed at about its own focal length from the flame, and serves to distribute the light uniformly over the slide.

CHAPTER XVIII.

THE EYE. TELESCOPES AND MICROSCOPES.

214. We may now proceed to give some account of the **human eye.**

Fig. 122 is a vertical section, in which C is the cornea, I the iris, P the pupil, L the crystalline lens, V the vitreous humour, and O the optic nerve.

The external shell of the eye is tough and horny, and of a white colour, except in front. It is called the *sclerotic*. The front part of it is transparent, and more convex than the rest. It is called the *cornea*. Behind the cornea is a cavity containing a watery liquid called the *aqueous humour*. Nearly at the back of this is the *iris*, which is an opaque

Fig. 122.

curtain with a round hole in the centre called the *pupil*. The iris is coloured. It is the part that is blue in blue eyes, brown in brown eyes, and so on; and it is full of muscular fibres which contract and lengthen of their own accord so as to alter the size of the pupil, making it small when exposed to strong light and large when exposed to darkness.

Behind this is the *crystalline lens*, which is a solid body, as transparent as the clearest glass, and built up of coats like an onion. Its shape is that of a very convex lens, more convex behind than in front. Behind it, is a very large cavity occupying the greater part of the eye, and filled with a jelly called the *vitreous humour*. The walls of this cavity are intensely black except the back, which is covered with a membrane sensitive to light, called the *retina*.

215. Rays from an external object at a proper distance for distinct vision are rendered convergent by the convexity of the front part of the eye, that is, the cornea and vitreous humour (which act like one body); and the crystalline lens renders them still more convergent. The lens would have no effect if its index of refraction were the same as that of the humours before and behind it; but it has a rather higher index of refraction than they have, especially in its central portions, and it thus acts in the same way (though not so powerfully) as a convex lens in air. For distinct vision to be obtained, the rays from a point of the object must converge to a point of the retina; in other words, a sharp image of the object must be depicted on the retina.

216. There is a difficulty to be surmounted here; for when a lens is fixed in front of a screen, and throws upon the screen a sharp image of an object at the distance of a mile, it will not give a sharp image of an object at the distance of a foot. As the object comes nearer, the distance of the lens from the screen needs to be increased. The mode in which the eye is accommodated to different distances appears to consist in the relaxation and contraction of muscles which surround the eye, and which, when they are contracted, squeeze it out to a greater length, thus increasing the distance between the crystalline lens

and the retina. The focal length of the lens is at the same time shortened by an increase in its convexity. When the muscles are relaxed, the eye (in the case of most people) is in correct adjustment for viewing very distant objects.

217. The retina, upon which the image is formed, is made up of the ends of nerve-fibres which lead to the optic nerve. These nerve-ends are sensitive to light, so that light falling upon them gives the sensation of seeing. If light came to them direct from external objects, without the intervention of apparatus for producing convergence, we should merely get a general impression of the sum total of light that comes to us from a landscape, instead of seeing its separate parts.

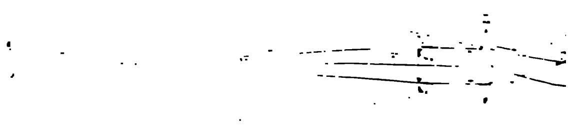
218. When we look at a near object with both eyes, the two pictures which are formed are slightly different in outline, and these differences give us the means of telling which parts of the object are nearest to us; in other words, they give us the perception of *relief*. This effect is successfully imitated in the **stereoscope,** in which two photographs, taken by two cameras side by side, are placed one in front of each eye. The two pictures combine into one as we look at them, and give us an irresistible impression of relief.

219. Before going on to describe *telescopes* and *microscopes*, it will be well to say a few words about **apparent size.** We have given some rules in art. 206 relating to the *actual* sizes of images; but the actual size of an image must not be confounded with its apparent size. The actual size can be stated in inches; the apparent size can be stated in degrees of angle. The apparent length of an image is measured by the angle contained between two lines drawn from the two ends of the image to the observer's eye. This angle, in fact, is what determines

... has a magnifying power of ...

220. Telescopes.—A telescope of the simplest kind ... glasses, one large and the other small, or ... mirror and a small lens. The large ... focal length and the greater ... is the image which is formed at ... when the instrument is pointed to a ... This image could be thrown upon a scr... could be viewed by the eye dir... convex lens of short focal leng... near to this image and enables us ...

... to explain how a telesco... lens above mentioned ...



... Telescope.

... A B is the inverted image which it for[m]... the distance of this image from the centre C being t... focal length of the object-glass. L is the *eye-glass*, a... $A' B'$ is the image which it forms of $A_1 B_1$. This sec[ond] image is what the observer sees. Its apparent size ... measured very nearly by the angle $A' C' B'$, which is ... same as $A_1 C'' B_1$; and this is much larger than the an...

$C B_1$, or its equal $A C B$, which measures the apparent
e of the object as it would appear to the naked eye.

If $A_1 B_1$ were midway between the two lenses, the escope would not magnify; for the two angles $A_1 C' B_1$ l $A_1 C B_1$ would be equal; and if $A_1 B_1$ were nearer to C in to C′ there would be diminution. The magnifican depends upon $A_1 B_1$ being further from C than m C′; and the magnifying power is computed by iding one of these distances by the other, or what is irly the same thing, dividing one focal length by the ier.

222. The following remarks will explain how the ure has been drawn.

Rays passing through C, the centre of the object-glass, e not bent; and the same remark applies to C′, the ntre of the eye-glass. Hence we can draw a straight ie through C from any point of the object to the corsponding point of the first image $A_1 B_1$. The object is pposed to be far away to the left, and the straight rays $C A_1$, $B C B_1$ come from the two ends of it to the two ds of the image. The lengths of $C A_1$, $C B_1$ are to be ade equal to the focal length of L. The eye-lens L′ is pposed to be at rather less than its own focal length m this first image; in fact, F is supposed to be the ncipal focus of L′, and it has another principal focus at the same distance on the other side. In practice distance $F P_1$ is very small compared with F C′.

We know that the ends of the second image A′ B′ ist be somewhere on the lines $C' A_1$, $C' B_1$, or on the itinuations of these lines, because the rays $A_1 C'$ and C′ will not be bent; and we can find how far off it is tracing the course of a ray from A_1 parallel to the is. We know that after passing through the eye-lens s ray will go to the principal focus F′. But to the

observer this ray will seem to come from A′. Hence we have only to produce this ray backwards till it meets the production of C A_1, and the point where they meet will be the point A.

By pushing the eye-lens in, or pulling it out, through a small distance, we change the distance F P_1, and this makes a great difference in the distance of A′ B′. As we make F P_1 diminish to nothing, we send A′ B′ further off to an unlimited distance; so that if F coincides with P_1 the observer must focus his eye as if he were looking at distant objects; and if he then push the eye-piece gradually further in, he will still be able to see distinctly by altering the focal adjustment of his eye, until he has brought A B to the nearest distance of distinct vision.

223. This kind of telescope is very much used for astronomical purposes; but as it shows things upside down, it is not convenient for ordinary terrestrial purposes.

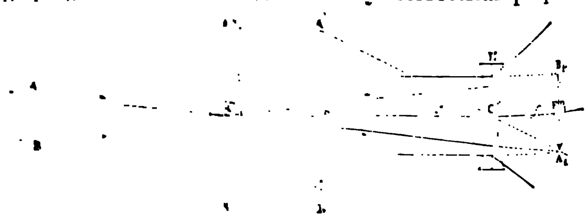


Fig. 224. Principle of Galilean Telescope.

Fig. 224 illustrates in the same way the formation of images when the eye-glass is concave. Here the rays on their way to form the first image A_1 B_1, which is inverted, are intercepted by the eye-glass, and made to form the erect image A B. This is the construction used for *opera-glasses* and *binocular field-glasses.*

In the ordinary terrestrial telescope, the arrangements for rendering the image erect are rather complicated.

224. In reflecting telescopes, instead of an object-

glass there is a concave mirror, generally called a *speculum*, which is the Latin name for *mirror*. It must not be of glass silvered at the back like a looking-glass; for the reflection from the front would interfere with that from the back; and inequalities in the glass, whether in its density or its thickness, would produce irregular refractions. The speculum is usually of solid metal, consisting of an alloy of copper and tin called *speculum metal*. This alloy is very hard and very brittle—harder and more brittle than glass. Of late years what are called *silvered specula* have been largely used instead. A silvered speculum is made by first grinding one face of a thick piece of glass into the proper shape, and then depositing upon its surface by chemical means a thin covering of silver—not quicksilver, but silver properly so called. These specula are much cheaper than the others, for glass is much easier to work than speculum metal.

225. The speculum of a telescope, instead of being at the end next the object, as an object-glass is, must be at the further end; and there are various contrivances to prevent the observer from standing in his own light, as he would do if he put his eye to the mouth of the telescope, and looked towards the speculum.

Sir William Herschel, with some of his gigantic telescopes, tried the plan of placing the speculum a little oblique, so that rays coming down the axis of the tube were reflected, not to the centre of the mouth, but to a point near one edge. This obliquity was found very injurious to good definition. A commoner plan is to place a small plane mirror just within the mouth, to catch the reflected rays and send them sideways, this mirror being set at an angle of 45°. The observer looks in through the side of the tube near its mouth, an eye-lens being employed, as in refracting telescopes, to magnify the

image. This kind of telescope was first made by S
Isaac Newton, and is called the *Newtonian Reflector*.

226. Another plan, more convenient for terrestrial pu
poses, is represented in fig. 125. M is the large conca
speculum, which has a hole in the middle for the o
server to look through with the aid of the eye-lens o

Fig. 125.—Gregorian Telescope.

rather eye-piece A B. m is a small concave mirror, whi
can be moved further or nearer by the focussing scre
V. The large speculum forms an inverted image; a
the rays from this image go on to the small mirr
which is at rather more than its own focal length fro
the first image, and therefore forms an inverted and ma
nified image of it at a greater distance, namely, just
front of the eye-piece. The second inversion undoes t
first, and this telescope (which is called the *Gregori*
therefore shows things erect.

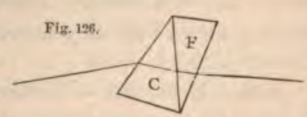
227. Chromatic Aberration.—We must now call

tention to a source of difficulty in the construction of lenses which does not exist in the case of mirrors. Blue light (as mentioned in art. 197) is more bent by refraction than red light; hence a lens acts more powerfully on blue light than on red, and the focal length of a lens is shorter for blue than for red. Ordinary light, in fact, contains a mixture of various colours, all having different focal lengths for one and the same lens. The consequence is that, instead of obtaining images with sharp outlines, we have fringes of colour where the edges ought to be. If only one kind of glass were available for making lenses, this difficulty could not be overcome, and the construction of a powerful and yet clear refracting telescope would be impossible.

In reflection there is no such separation of colours, and Newton had recourse to reflection as the only means of constructing a good telescope.

228. Achromatic Lenses.—Since his time it has been found that by joining together two lenses, one convex and the other concave, of two different kinds of glass, the separation of colours can be greatly diminished, and refracting telescopes can be constructed which give as sharp outlines as reflecting telescopes. Flint glass separates the colours more than crown glass; so that, if we construct a flint-glass prism and a crown-glass prism with such angles that they give upon the whole the same amount of deviation, the flint-glass prism will bend the blue rays more and the red rays less than the crown-glass prism, and if we pass a beam of light through the two prisms in succession, with their bases turned opposite ways, as in fig. 126, blue will be bent one way and red the other. If we want to pre-

Fig. 126.



blue from red, we n
... glass prism by givi
... power the flint-g
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al foci, the small arrow A B is the object, and the rrow the image. Rays from A and B parallel to is will be refracted to F, and will seem to come he ends of the image. Also the rays A O and B O ass straight on, and will seem to come from the two of the image. If the object is moved nearer to *f*, nage will move further off, and we can thus send it off as we like. If the object is beyond *f* it will e seen distinctly. If the simple microscope is a g one, the focal length O *f* will perhaps be $\frac{1}{4}$ of an and the distance of the object from O will be bly the same, while the image will be at a distance me feet. The apparent size will be measured by ngle A O B, that is by the angle which the object nds at a distance of $\frac{1}{4}$ of an inch; and to know advantage we gain by the use of the microscope, we compare this angle with the angle which the object l subtend at 6 inches, if 6 inches is the nearest nce at which we can see a thing distinctly with the l eye; the magnifying power would then be 24. nearest distance of distinct vision is very different ifferent people; and the magnifying power of a scope is generally stated by comparison with a distance of 10 inches, so that a simple microscope with a length of $\frac{1}{4}$ inch would be said to have a magnifying r of 40.

l. The **compound microscope** resembles a telescope ving two lenses; but the object lens, or *objective*, as called in a microscope, is small and of short focal h, and the image which it forms is not formed at rincipal focus, but much further off. The eye-piece ch the same as in a telescope, and serves the same se—that of making the image look larger than it l if we viewed it without any eye-piece.

[illegible] medium taking them in [illegible]

[illegible] speak of waves of sound, [illegible] things as waves of light and [illegible] be supposed that they are [illegible] water-waves the surface [illegible] that we have changes of [illegible] sound-waves we have changes [illegible] continually tending [illegible] of the water to a uniform [illegible] are continually tending [illegible] uniform density. Again, [illegible] and a disturbance [illegible] in circular waves; [illegible] in the midst of [illegible] horizontally, but [illegible] in *spherical* [illegible] air gets a [illegible] then another [illegible] symmetrical all [illegible] make the particles [illegible] towards and away [illegible] convey sound [illegible] line along which [illegible] with and against [illegible] in a straight line.

[illegible] small portion of air [illegible] The squeeze [illegible] and when the [illegible] rarer than it was [illegible] there are dense and [illegible] propagation, just [illegible] alternately along a line [illegible] surface of water-waves.

There is a curious connection between the changes of density and the backward and forward swings.

As long as a particle is denser than ordinary, its motion is forward, and its velocity is exactly proportional to its excess of density; on the other hand, during the time that its density is less than ordinary, its motion is backward, and its velocity proportional to its defect of density. If we know what the changes of density are, we can compare the velocities of the particles with the velocity of sound; for instance, when the density of a particle differs from the ordinary density by one part in a thousand, the particle is moving with a velocity which is one thousandth of the velocity of sound. These results of mathematical reasoning we must ask our readers to take upon trust.

251. We have now to state a property of wave-motion, which is almost self-evident, but it will first be necessary to explain the terms **wave-length** and **period.**

Let us suppose that the waves are quite regular; then everything happens over and over again at equal intervals of time. The length of one of these equal intervals of time is called the *period.* Whatever the particles are doing at one instant, they are doing exactly the same a period later.

Again, at a given instant, a number of different particles are doing the same thing. Particles which lie on the same spherical surface described about the source, and are all doing the same thing at the same time, are said to be on the same *wave-front.* There are a number of wave-fronts, at different distances from the source, that are all in the same condition at a given moment; and the distance between one of them and the next is called the *wave-length.* If we are dealing with waves on the surface of water, the wave-length is the distance between two successive crests. The property we have to state is, that *the*

waves advance in one period through a distance of one wave-length; for example, if we think of waves on water, it is obvious that when a particle is in its highest position it is at the crest of one of the waves, and that it will be in its highest position again when the crest of the next wave reaches it. This property of wave-motion enables us to calculate the velocity of propagation if we know the wave-length and the period. It will be calculated by dividing the wave-length by the period; for velocity is always reckoned by dividing the distance traversed by the time occupied. Or again, if the velocity of propagation and the period are known, we can calculate the wave-length by multiplying them together; for instance, taking the velocity of sound as 1100 feet per second, if the period is $\frac{1}{100}$ of a second the wave-length will be 11 feet, and if the period is $\frac{1}{1100}$ of a second the wave-length will be 1 foot. When the velocity of propagation is the same for long as for short waves (which is the case for sound), the wave-length is directly as the period.

Since a period is the time in which a particle makes one complete vibration, the number of vibrations in a second is the number of periods in a second; for example, if the period is $\frac{1}{100}$ of a second, the number of vibrations in a second is 100.

252. As regards the *loudness* of a sound at different distances from the source; when the sound is produced in an open space, and can spread downwards, upwards, and in all directions, the law is the same as for light or radiant heat under the same circumstances—that is to say, the loudness will be inversely as the square of the distance from the source; so that if we double the distance, the source will need to be strengthened fourfold to keep up the same loudness. The reason of this law is found in the fact that the areas of spherical surfaces are

as the squares of their radii. When a sound has advanced through double distance from the source, it has spread over a spherical surface of fourfold area, and has been proportionally weakened.

In the propagation of sound through a tube, this spreading out into spheres is prevented, and sounds accordingly remain audible at very great distances. Hence the efficacy of *speaking-tubes*. In experiments with empty sewer-pipes at Paris, it was found that the report of a pistol could be heard at distances varying from 700 yards to $6\frac{1}{4}$ miles according to the diameter of the sewer, the distance increasing with the diameter.

The velocity and wave-length are the same in propagation through a tube as in open space.

CHAPTER XXI.—MUSICAL SOUNDS. GAMUT.

253. The difference between musical sound and mere noise is that the waves of musical sound are much more regular than other sound-waves. A great many successive waves are exactly alike, and when changes occur they occur very gradually.

We may have either simple or compound musical sounds. The sound emitted by a tuning-fork is about the simplest we can have. The sounds emitted by a violin, on the other hand, are highly compound; that is to say, though only one string is sounding, it is giving several notes at once. The notes of a piano are compound; when we strike one of the bass notes, we can hear, if we listen attentively, its upper octave as well, and another note a fifth higher than this; several still higher notes are sometimes present. Of course we can also produce compound sounds by striking several notes at once.

254. Compound sounds have compound waves, and this subject requires some explanation. The waves of the sea are covered with smaller waves, which we call ripples, and which do not travel near so fast as the large waves. It is a rule for water-waves that the velocity depends upon the wave-length—the greater the wave-length the greater the velocity; but this is not the case with sound waves, their velocity is the same for all wave-lengths; hence sound-waves as they advance carry their ripples with them, instead of leaving them behind and getting new ones as water-waves do.

In ordinary cases of compound sound-waves, the different simple waves which are present combine their effects by simple addition and subtraction; so that the actual density at a point can be computed by adding all the excesses and subtracting all the defects of density due to the simple waves considered separately; and the velocity of a particle can in like manner be computed by adding and subtracting the forward and backward velocities due to the simple waves.

255. There is a close resemblance between the movement of a particle in simple sound-waves and the movement of a pendulum. They both swing from side to side, moving quickest in the middle, and more and more slowly as they get near the turning points, where they are for an instant at rest. In fact the only difference is that the particle moves in a straight line, and the bob of the pendulum moves in a line which is slightly curved.

256. Fig. 136 shows the kind of curve that is obtained by causing either a pendulum or a tuning-fork to write its own vibrations upon a sheet which travels uniformly in a direction at right angles to the line of vibration. There are no corners, and no straight lines, but a succession of easy bends in opposite directions. At *b* the pendulum is at one extremity of its swing, at *d* it is at

the opposite extremity, and at a, c, and e it is at the middle point. To make a tuning-fork trace a curve like this, we fix its handle in a firm stand, and attach a light thin piece of brass pointed at the end to one of its prongs to serve as a writing point.

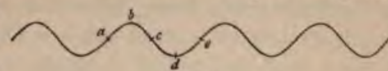


Fig. 136.

The stand contains an arrangement for letting a small sheet of glass slide down in grooves by its own weight, at such a distance from the fork that the writing point barely touches the glass. We smoke one side of the glass, and after setting the fork in strong vibration allow the glass to slide down past it. The tuning-fork will make a large number of vibrations during the short time that the glass takes to fall, and it will therefore trace a curve with a large number of bends, each double bend indicating one complete vibration. By mounting two tuning-forks in the same stand, we can make them both write on the same piece of glass, and can thus compare the numbers of vibrations that they make in the same time.

257. Instead of a tuning-fork we may use a thin plate of steel T, fig. 137, firmly clamped at one end B, and having a writing point A fastened to its other end. The writing may be executed on a piece of smoked paper put round a cylinder which has a screw cut upon its axle V D, so that, as the handle is turned, the cylinder not only revolves but also travels endways; the writing may thus be made to form a continuous trace going round the cylinder in screw fashion from end to end. If only a short trace is required, the spring may be started by giving it a pull to one side and letting it go; but for long-continued vibration it is better to use a well-rosined fiddle-bow, applying it from time to time when the vibrations are becoming too feeble.

in a second is called *low*. The ordinary human voice ranges from about 80 or 90 vibrations per second, in the lowest bass note, to 700 or 800 in the highest treble.

261. Musical Intervals.—Musicians employ certain definite *intervals* or differences of pitch; and the chief test of a good musical ear is the power of judging these intervals with precision, both when the two notes are sounded together and when they are sounded separately.

The first interval in order of importance is the *octave*. It is extremely easy to judge with precision, and in the tuning of pianos and organs all the octaves are made exact. In this interval the upper note makes exactly twice as many vibrations as the lower one.

The next in point of importance is the *fifth*. It can be judged with almost as much precision as the octave, and gives an extremely smooth effect when the two notes are sounded together. The upper note makes half as many vibrations again as the lower one—in other words, the vibrations are as 2 to 3. Thus if we start from a note of 600 vibrations per second, and rise a fifth, we obtain a note of 900 vibrations, and if instead of rising we fall a fifth, we obtain a note of 400 vibrations per second. To rise a fifth is to multiply the vibrations by $\frac{3}{2}$, and to fall a fifth is to multiply them by $\frac{2}{3}$.

262. When the vibrations are as 3 to 4 the interval is called the *fourth*; and if we first rise a fifth, and then a fourth, we rise an octave altogether; for we multiply the original number of vibrations, first by $\frac{3}{2}$, and then by $\frac{4}{3}$; we therefore on the whole multiply it by $\frac{3}{2} \times \frac{4}{3}$, which is equal to 2.

A musician would express this fact by saying that a fifth and a fourth together make an octave. Adding two intervals means multiplying together the two fractions which express them.

In tuning pianos and organs, the fifths and fourths are made very nearly but not quite exact; the fifths are made a very little too small, and the fourths just as much too great, but the inexactness is so very slight that hardly any one but a professional musician could detect it.

The interval expressed by the ratio of 4 to 5 is called the *major third*, and 5 to 6 is called the *minor third*, but tuners depart very widely from these exact ratios.

The intervals expressed by the ratios of 8 to 9 and of 9 to 10 are called respectively a *major tone* and a *minor tone*, and 15 to 16 is called a *limma*, but tuners depart altogether from these theoretical values.

253. The origin of the above names will be understood from an inspection of the following scheme, which sets forth the relations existing between the eight notes of the theoretical octave, the word *octave* being used not only to denote the interval between the first and last (as we have used it above), but to denote the eight notes themselves as well. The first (that is, the lowest) of the eight notes is called the *key-note*, and the last (or highest of the eight) is regarded as the key-note of another set of eight notes, the octaves of these. The scale thus repeats itself over and over again.

We give in the first line the names of the eight notes in the tonic sol-fa system, in the second line the smallest whole numbers that will express the relative numbers of vibrations, in the third line the ratios of these numbers to the first. The fractions in this third line accordingly express the relation between each note of the scale and the key-note, and the names of the corresponding intervals are placed beneath them. The name *fifth* has been given to the interval $\frac{3}{2}$ because it is the interval from the first note to the fifth note, and so on for the others, the name

[illegible] means eighth) being given [illegible] first note to the eighth note.

[illegible]	[illegible]	Mi	Fa	Sol	La	Si	Do
[illegible]	[illegible]	[illegible]	32	36	40	45	48
[illegible]	[illegible]	[illegible]	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
[illegible]	[illegible]	major third.	fourth.	fifth.	sixth.	seventh.	octave.

284. [illegible] the intervals between the succes[illegible] [illegible] we obtain the following ratios [illegible] them in lowest terms.

[illegible]	[illegible]	[illegible]	$\frac{40}{36}$	$\frac{45}{40}$	$\frac{48}{45}$
[illegible]	[illegible]	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

[illegible] are only three different interval[illegible] [illegible] The largest of them (expresse[illegible] [illegible] the next largest ($\frac{10}{9}$) th[illegible] [illegible] the *limma*. To com[illegible] [illegible] let us see what two of thes[illegible] [illegible] $= 1\frac{31}{225}$, which i[illegible] [illegible] is therefore greater than $\frac{9}{8}$, an[illegible]

285. [illegible] keys of a piano or organ were tune[illegible] [illegible] numbers, the music would be mu[illegible] [illegible] present for pieces in which no flats [illegible] [illegible] but some other pieces of music would con[illegible] [illegible] worse than at present. Tuners adopt a co[illegible] [illegible] compromise. They make the intervals whi[illegible] [illegible] be $\frac{9}{8}$ and $\frac{10}{9}$ equal to each other as nearly [illegible] be, and the interval which ought to be $\frac{16}{15}$ they ma[illegible] [illegible] half of either of these.

As this system of tuning does not consist in simply following one's ear, but in judging exactly how far to depart from that which sounds best, it requires not only a good ear but practical experience. No tuner ever attempts to tune each note by comparison with the one next to it, for this would involve too difficult an exercise of judgment. The plan adopted is, first to tune the octaves of C, and then to step up and down from these by fifths and fourths. The reason is that fifths and fourths are made more nearly true than the other intervals. Twelve *fifths* on the piano make seven octaves, and twelve *fourths* five octaves, and it will be found, on making the calculation, that the twelfth power of $\frac{3}{2}$ is nearly equal to the seventh power of 2, and the twelfth power of $\frac{4}{3}$ to the fifth power of 2.

266. In singing without instrumental accompaniment, it is not necessary to adopt any such compromise; for though a pianist has only twelve definite steps by which he can ascend an octave, a singer can make his steps of any length he pleases. A similar advantage is possessed by players on the violin, violincello, &c. Hence purer harmony is attainable by string-bands, and by choirs singing without accompaniment, than is possible in performances in which organs or pianos take part.

Chapter XXII.—STRINGS. OVERTONES. PIPES.

267. Vibrations of Strings. — A tightly-stretched string may be excited to vibration either by plucking it, as in the harp, or striking it, as in the piano, or rubbing it with a rosined bow, as in the violin. If the string were attached at both ends to firm and massive supports, hardly any sound would be given. The string itself is so thin

that it cuts through the air instead of pushing it,
order to produce strong vibrations of the air it m
aided by a *sounding-board*, that is, by a board suffi
thin to be easily agitated by the action of the
and having a surface of considerable extent by w
can act upon the air. In the piano, the sounding-b
a large flat board, to one side of which a piece call
bridge is fastened. The strings pass over this brid
press it strongly against the board; and when a st
vibrating, this pressure is alternately increased and
ished. In the violin there is also a *bridge*, answeri
same purpose, and the body of the violin plays th
of the sounding-board.

268. The pitch of the note given by a string d
partly on its tightness;—as we tighten it the vibr
are quickened, and the pitch rises. It also deper
the length of the string. A violin player, by pr
down a string with his finger, shortens the vibratin
tion, and produces a higher note than that of th
string.

The number of vibrations in a second is invers
the length, and directly as the square root of the te
Thus we can double the number of vibrations eith
halving the length or by quadrupling the tension.

Comparing a thick string with a thin one, or com
two strings of different materials, the rule is, that i
lengths are the same, the stretching forces whic
make them yield the same note are directly as
masses—in other words, directly as their weights.

269. Thus far we have been speaking of the
mental note of a string. This is the note which it
when simply plucked with the finger, and which it u
gives when rubbed with a bow. But by dexterous
agement we can make a string give a series of

tones called *overtones.* If we touch it lightly at the exact centre of its length, and bow one half of it, it will give the octave of the fundamental tone—that is, it will vibrate twice as fast. In like manner, by touching it at one-third, one-fourth, or one-fifth of its length from one end, we can make it vibrate three, four, or five times as fast as when giving the fundamental tone. In all these cases the

Fig. 139.—String vibrating in three Segments.

string is able to keep up the note, when we cease touching it and leave it to itself. The experiment is represented in fig. 139, which also shows the nature of the vibrations produced. The string here divides itself into three equal portions, each vibrating as if it were fixed at the ends; and the note emitted is the fundamental note of a string whose length is equal to one of these portions. The points of junction between one of these portions and the next are called *nodes,* and are at rest or very nearly at rest. A paper rider laid on a node will keep its place, while those placed on any other part will be thrown off, as shown in

... tones. Fig. 14 will assist in giving a correct idea of ... motion of a string when giving an overtone. The con... line represents one extreme position of the string, and the dotted line the other extreme position.

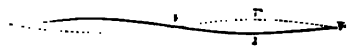


Fig. 14.

It is easy, by this mode of operating, to ... string ... as many as ten different notes. Their ... are shown in the following list.

	Relative Number of Vibrations	Musical Designation
[illegible]	1	Do_1
[illegible]	2	Do_2
[illegible]	3	Sol_2
[illegible]	4	Do_3
[illegible]	5	Mi_3
[illegible]	6	Sol_3
[illegible]	7	not exact
[illegible]	8	Do_4
[illegible]	9	Re_4
[illegible]	10	Mi_4

... beneath the names in the ... notes of the same name ...

... Wind-instruments.—In whistles, flutes, fifes, ... organ pipes, the vibrating body ... is the column of air contained ... Some kind of mouth-piece is required ... but this has hardly any influence ... the pitch depends on the length and ... a small extent on the width of the column of air which the pipe incloses. Some pipes are open at the end remote from the mouth-piece, and others are closed: the former are called *open pipes* and the latter *stopped pipes*. An open pipe gives about twice as many vibrations in a second as a

stopped pipe of the same length; hence, by closing the end of an open pipe, we make its pitch fall by about an octave. We are here speaking of the fundamental tones in both cases.

271. It is generally possible, by blowing more strongly, to make the pipes give overtones. The overtones of an open pipe follow approximately the same law as those of a string (see art. 269), but there is a sensible departure from exactness, the overtones being flatter than the simple numerical law of art. 269 would make them. This is especially the case when the pipes are broad in proportion to their length, as in fig. 141.

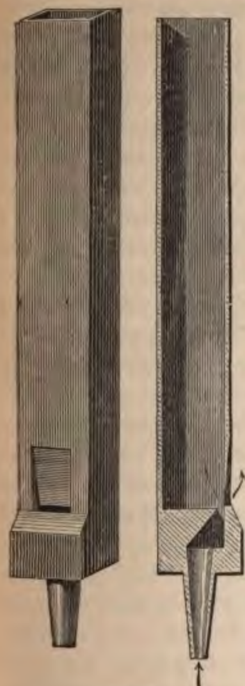


Fig. 141.

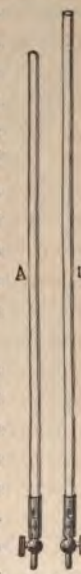


Fig. 142. Tubes for Overtones.

Very narrow pipes like those shown in fig. 142 give overtones in close accordance with the simple law, and give them more readily than the fundamental tone itself. These narrow pipes are very interesting for acoustic experiments, but they are not sufficiently under control to be used in organs.

The overtones of stopped pipes follow a different law; their vibrations are approximately 3, 5, 7, 9, &c. times as rapid as those of the fundamental, all the even multiples being absent.

... tissue-paper over a light ... as to make it like one end ... into a pipe like that ... is attached to the ... stretched paper is hori- ... we shall find that, when ... the paper membrane ... the pipe. A loud rust- ... is near the top of the ... the rustling becomes ... when the membrane is ... just below the middle of ... the rustling begins ... rustling is a *node* or ... from both ends, and ... ends, thus giving it ... expansion. When the ... these squeezes, ... it retains its posi- ... giving its first over- ... as the funda- ... that there are ... and the other ... The particular ... a pipe depends ... formed. In a stopped ... there is no node ... For its first overtone, ... third of its length from the ...

273. Flute Pipes. In the pipes which we have thus ... the mouth-piece through which the wind ... resembles that of a common whistle. The wind passes through a long narrow orifice, opposite to which

is the edge of a wedge (fig. 141). The sheet of air which issues from the orifice grazes the wedge, and passes on outside the pipe, waving backwards and forwards in accordance with the vibrations of the body of air within the pipe. In blowing a flute, the wind is, in like manner, directed by the lips of the performer against a sharp edge, which answers the same purpose as the wedge in these pipes.

Fig. 143.—Reed Pipe.

274. Reed Pipes.—There is another class of wind-instruments, in which the mouth-piece contains a spring, which in one position opens a passage for the wind, and in another position closes it. Instruments with this kind of mouth-piece are called *reed* instruments. The harmonium, the concertina, and the reed-pipes of organs, belong to this class. Toy trumpets furnish a more familiar example. Figs. 143, 144, represent two reed organ-pipes, with some of the interior parts exhibited separately.

275. To begin with fig. 143, which represents a reed pipe taken to pieces; l is the spring, which is a thin, flat strip of steel, slightly curved, so that it may leave a chink open at the lower end when pressed close home in the middle by the regulating wire z, which is used for tuning. r is a metal tube, closed at the lower end, but with a wide opening on one side, through which the air would pass if the spring were removed. If the spring were pressed down for its whole length, so as completely to close this opening, air could not pass through the pipe at all. When wind from the

bellows enters the pipe through the round tube at th
bottom, it first escapes through the chink at the botto
of the spring; but while so doing, it blows the sprin
against the tube and closes the passage. The sprin
then recoils, is again blown to, and so on.

Fig. 144.—Free Reed.

These alternations give rise
vibration of the whole body of a
within the pipe, and the number
vibrations made by this body of a
is the same as the number made b
the spring. The rapidity of vibr
tion depends mainly upon the lengt
and flexibility of the free portion
the string; and if the regulatin
wire z is pushed further down,
as to shorten the free portion of th
spring, the vibrations will be quic
ened. But the spring is to som
extent controlled in its movemen
by the body of air which it has t
keep in vibration, and does not v
brate with exactly the same rapidit
as it would in the open air. Th
pitch of the note actually produce
accordingly depends, partly on th
spring, and partly on the size an
shape of the pipe. It is also found to depend ver
much on the strength of the blast, the pitch rising as w
blow more strongly.

276. Fig. 144 consists of three parts, one representin
a complete pipe; another on a larger scale showing th
upper part, which can be lifted out of the lower; and th
third, on a still larger scale, the spring and its setting. T
spring here is a thin strip of steel as before, but it is rath

smaller than the opening over which it is fixed; and when set in vibration by blowing the pipe, it passes through the opening, first in one direction and then in the opposite. A spring thus arranged is called a *free reed*, whereas the arrangement previously described is called a *striking reed*. The pitch of a pipe fitted with a free reed is not much affected by varying the strength of the blast. Free reeds are used in the harmonium and concertina; striking reeds are used for the *trumpet stop* in organs. The clarinet, oboe, and bassoon are reed-instruments; the passage for the wind from the performer's mouth into the instrument being alternately opened and closed by the vibration of thin pieces of ivory. In brass instruments, the lips of the performer vibrate and play the part of a reed.

Chapter XXIII.

RESONANCE. VOICE AND HEARING. BEATS. SIREN. CHLADNI'S FIGURES. PHONOGRAPH.

277. Resonance of a Column of Air.—The column of air contained in an organ-pipe, or in any tube of similar shape, has certain notes proper to it. If one of these notes is produced by an external source within hearing-distance of the pipe, the air in the pipe is set in much stronger vibration by it than by a note of different pitch; and if the external source of the note be suddenly stopped, the pipe keeps up the sound on its own account for a sensible time.

We can understand how this is by the analogy of a heavy weight hung by a long string,—say ten feet long. If we give it a push that sends it an inch in one direction from the position in which it has been hanging at rest, it

will come back and swing nearly as far to the other
If, when it again returns to the lowest point, we gi
a second push just like the first, it will go further
it did the first time; and by continually repeating
operation we can make the weight swing through ar
of several feet. This result depends upon the inte
between the pushes being the same as the natural pe
of vibration of the suspended weight. The push n
always be delivered so as to help the pendulum or
way and not to oppose it; and if we were to make
pushes quicker or slower in such a ratio as 2 to 3, or
4, or 4 to 5, some of the pushes would help it on its
and others would oppose it. The same thing is true
any vibrating body. If we give it a series of pushe
pulls exactly in time with the period in which it can
on vibrating of itself, the effects will accumulate, and
continual repetition of feeble impulses will produce la
vibrations. When the vibrating body which is t
affected is a confined body of air, the effect is ca
resonance, and the body of air is said to *respond* to the
ternal source which thus acts upon it.

If a vibrating tuning-fork is held to either of the
openings of an organ-pipe which has the same note
the fork, the pipe will respond with sufficient lo
ness to be heard all over a large room; or instead of
organ-pipe a flute may be used, the fork being h
either to the hole for blowing or the open end, while
flute is fingered as if for producing the note of the f
in the ordinary way. The note of the tuning-fork
these experiments may be either the fundamental ton
the pipe or any one of the overtones.

278. Helmholtz's Resonators.—Resonance is rende
more audible to a single listener by means of the
nance globes or *resonators* contrived by Helmholtz, on

which is shown in fig. 145. There is a large opening at one end, and a small opening at the other. Each resonator responds to one particular fundamental tone, which depends upon its size. The resonance can be exhibited to an audience in the same way as the resonance of a pipe, that is by holding a vibrating tuning-fork of the proper pitch to the large end; but even when the tuning-fork is several yards distant, the resonance of the globe can be heard by a person who puts the small end of the resonator into his ear, while he directs the large end towards the distant fork.

Fig. 145.—Resonator.

279. These resonators are much used for showing the compound nature of most musical sounds; for example, of the notes of the human voice. They are generally made in sets of 10, the note of the largest being C in the second space of the bass clef, or more accurately C of 128 vibrations per second. This we will call resonator No. 1. Resonator No. 2 has just half the dimensions of No. 1, and its note has twice as many vibrations. No. 3 responds to a note of three times as many vibrations as No. 1; and so on. When C of 128 vibrations is sung, not only No. 1 resonator responds to it, but also most of the others; showing that the sound given forth by the singer is not a simple tone, but contains these higher tones mingled with the fundamental. On the other hand, if the same note C of 128 vibrations is produced by a large *tuning-fork*, No. 1 resonator is the only one that

other. The 100th push from the first will, however, again concur with the 101st push from the second; hence it is clear that the loudness produced by concurrence will occur once for every 100 vibrations of the slower source or every 101 vibrations of the quicker.

284. **Siren.**—Figs. 146, 147 represent an instrument

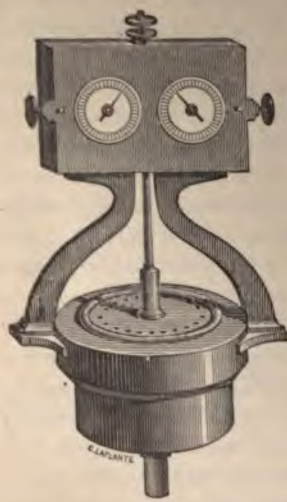


Fig. 146. Siren. Fig. 147.

which has been very much used for counting vibration It is called the *siren*.

A round plate pierced with a number of equidistan holes arranged in a circle revolves rapidly. Immediate beneath it, and nearly touching it, is a fixed plate, wi the same number of holes arranged in a circle exact under the other circle. The holes in the upper plate w come opposite to the holes in the lower plate sever times in each revolution—in fact as many times as the

are holes in either plate; and air from a bellows below is driven up through them. The issuing air accordingly makes as many vibrations in one revolution as there are holes in either plate. The number of revolutions is made to register itself in the following way. The upright stem which carries the revolving plate has a screw cut upon it, which engages with the teeth of a wheel, as shown in fig. 147, and makes this wheel revolve. A hand on the other side of the instrument is attached to the axis of this wheel, and traverses a dial, with divisions marked upon it which correspond to revolutions of the revolving plate, and there is a second dial with divisions on it which correspond to whole revolutions of the first hand. These are shown in fig. 146.

285. The instrument is usually constructed so as to be driven by the same wind that produces the sound. This is managed by giving a slope to the holes in the revolving plate, and an opposite slope to the holes in the fixed plate, so that the air impinges against one side of the holes in the revolving plate, as shown in fig. 147. The speed can be regulated either by the strength of the blast or by applying friction with the finger to the revolving stem. The siren can thus be brought into unison with any source of sound—a tuning-fork, for example; and the number of vibrations made by this source in a given time will thus be determined. The figures show two buttons, one on each side of the case containing the toothed wheels. By pushing one of these buttons (the right-hand one in the second figure) the case is pushed a little way to the left, and the toothed wheels are thus put out of connection with the screw. By pushing the other button they are put into connection again. In making an observation to determine the pitch of a source, it is usual to keep the wheels out of connection till the

siren has been brought into unison with the s
then suddenly to put them into connection at
minute as shown by a watch. At the expirati

Fig. 148.

minute, or
time measur
watch, the w
suddenly put
connection aga
hands on the d
thus be sta
when the readi
taken. One r
must be taken
the connection is
and another aft
has ceased, and
difference of the
readings will give
number of revoluti
which must then
multiplied by the nu
ber of holes. This giv
the whole number
vibrations; and know
ing the time occupied
it is easy to calculat
the number of vibra
tions per second.

Fig. 148 represents a stand with bellows for showing experiments with the siren or with organ-pipes.

286. Chladni's Figures.—Fig. 149 represents a very striking experiment on the vibration of a plate. A square plate of brass, firmly held at its centre, is bowed at one edge with a strong fiddle-bow rubbed with rosin, and can thus

be made to give several different notes, of definite pitch, though somewhat harsh in quality. When sand is sifted over the plate it immediately runs to the *nodal lines*, and thus forms definite figures, one of which is here

Fig. 149.

shown. These nodal lines reveal the mode in which the plate is vibrating. They are the places of rest (like the fulcrum of a see-saw), about which the portions of the plate oscillate, one portion going up when the adjoining portion goes down. When the note changes, the figure changes also, the figures with fewest segments belonging generally to the lowest notes. The production of any particular figure is aided by touching the plate at a nodal line, as is done by a thumb and finger in the illustration, and the bow must be applied at a distance from nodal lines. Thick plates are the best for

giving figures of few segments, and thin plates ar
best for figures of many segments. Some of the fi

Fig. 150.—Chladni's Figures.

obtained by using plates of other forms are show
fig. 150.

287. Phonograph.—Various attempts have been
to imitate speech by mechanical means, but none of
have been so successful as Edison's *phonograph.*
instrument is not constructed in imitation of the o
of speech. It is not even a wind-instrument, b
based on the principle that similar vibrations, in
ever manner produced, will give similar sounds
thin plate of iron, carrying a writing point, is first
to vibrate by the voice of a person speaking loudly
his mouth just in front of it. The writing poin
consequence of the vibration of the plate to which
fastened, makes indentations upon a sheet of t
which is moved past it. These indentations furnis
means of reproducing the spoken words. For this

pose, it is only necessary to pass them under the writing point again at about the same speed as before. They will raise and let down the writing point and plate in nearly the same manner as they rose and fell before, and the plate, by acting on the air, reproduces the condensations and rarefactions of the speaker's voice with sufficient power to be heard all over an ordinary apartment.

288. Fig. 151 represents the usual form of the instrument. The tinfoil is put round the cylinder B, and

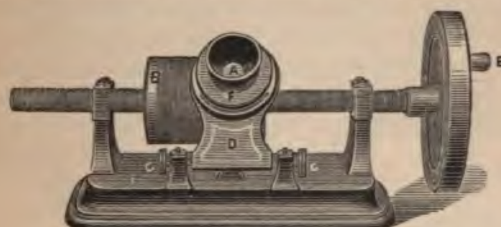


Fig 151.—Phonograph.

lightly fastened to it with cement. This cylinder is covered with a spiral groove like a screw-thread, and it is necessary that the writing point should always be opposite the groove. This end is attained by cutting a screw-thread on the axle of the cylinder, the distance between the threads on the axle being the same as on the cylinder itself. The voice is directed into the funnel A, the bottom of which is formed by the thin iron vibrating plate; and the writing point, which is of platinum, is fastened to the middle of this on the under side. The heavy frame D, which carries the funnel and vibrating plate, is mounted on a hinge at the bottom, and by its weight presses the writing point against the tinfoil. To prevent it from pressing the point so far down as to

groove the [illegible], a stop is provided, which takes the w
when the point is at the proper depth. This stop
be regulated by an adjusting screw; and two
screws C C, which are shown in the figure, serve
adjusting the point to the exact centre of the groove

MAGNETISM.

CHAPTER XXIV.

AGNETIC ATTRACTIONS AND REPULSIONS. GNETIC NEEDLE. MAGNETIC INDUCTION.

9. **Magnets** possess two well-known and very re-able properties—that of attracting iron and that of ing to the north. They are generally made of the est steel, and any piece of steel e converted into a magnet.

Fig. 152.

0. For showing the attraction on, magnets of the horse-shoe are commonly employed, and ones can be readily procured y-shops. They are generally hed with a piece of iron called *keeper*, which is firmly held st the feet of the magnet by tion; and when the magnet l by, the keeper should always its place, as it prevents the et from losing its strength time. Fig. 152 represents a ound horse-shoe magnet, made veral thin plates fastened face e. These are generally more powerful than magnets of one piece, because it is easier to magnetize pieces of steel than thick ones. The middle plate resented as projecting a little beyond the others, and

its ends are in contact with the keeper, which is furnished with a hook, on which a heavy weight is hung to exhibit the lifting power of the magnet.

Fig. 153.

291. For showing the pointing of a magnet to the north, a straight piece of steel made thin and light is generally employed. It is called a **magnetic needle.** It must be balanced in such a manner that it will take a nearly horizontal position, and must be free to turn round in a horizontal plane, fig. 153. For this purpose it is usually furnished with a small hollow cup of steel or agate, which rests, mouth downwards, on a steel point. The lower part of the figure shows the needle as mounted in actual use; the upper part shows the under side of the needle and cup. This is the arrangement adopted in ordinary portable compasses like that shown in fig. 154.

Fig. 154.

292. We can magnetize a common sewing needle by drawing it several times from point to head across one of the feet of a horse-shoe magnet, or one end of any strong magnet; and we can float it in water with perfect freedom to turn by running it through a little square pillar of cork, as in fig. 155. It will immediately turn into such a position that one of its ends points north and the other south. If, after performing this experiment, we draw the needle out of the cork and stroke it 10 or 12 times on the other foot of the horse-shoe, still stroking from point to head as before, we shall find, on thrusting the needle once more into the cork and floating it, that its position is reversed; the end which previously pointed to the north now points to the south.

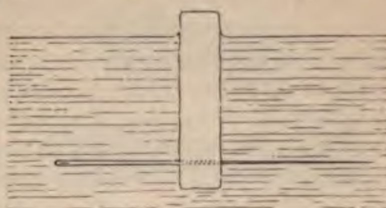


Fig. 155.

We may vary the experiment by using always the same foot of the horse-shoe, and comparing the effect of stroking from point to head with that of stroking from head to point; we shall find that the needle points opposite ways in the two cases. We can thus reverse the polarity of the needle, either by stroking the needle in opposite directions on the same pole, or by stroking it on opposite poles in the same direction. If we stroke it in opposite directions on opposite poles the polarity will not be reversed; stroking from point to head on one pole has the same effect as stroking from head to point on the other pole.

We have here used the word *pole* as another name for

either of the ends of a magnet. When a magnet is freely balanced, and no other magnets are near to disturb it, it turns one of its poles to the north and the other to the south.

293. Now let us try some experiments on the behaviour of poles towards one another.

Take a number of sewing needles all just alike, and to prevent confusion stroke them all from point to head on the same pole of a strong magnet, one at a time. It will be found that there is attraction between the point of one and the head of another, so that one of the needles can be dragged about by touching its head with the point of another or by touching its point with the head of another. On the other hand, two points repel each other, and so do two heads. The repulsion is not easily shown with needles lying on a table, but if we float one of the needles with a piece of cork in the manner just described, or if we suspend it by tying a thread round its middle so that it balances in a horizontal position, another needle brought near it will repel it when point is presented to point or head to head.

A north pole repels a north pole and attracts a south pole. A south pole repels a south pole and attracts a north pole; or, to put the same thing more shortly, *like poles repel each other; unlike poles attract each other.*

294. If we break one of our needles in halves, we find that each half is a complete magnet, the broken ends being poles as well as the original ends. These halves can again be broken, with the same result, and so we may go on till the pieces become too small to work with. It thus appears that the peculiar property of a magnet, which distinguishes it from ordinary unmagnetized steel, is distributed through its whole substance. Every particle of a magnet is itself a magnet.

295. Instead of thus breaking up a magnet, we can perform the converse experiment and build up a magnet by putting some of our needles together. The easiest way to do this is to place them end to end, with unlike poles in contact at every junction. They will thus adhere together by their mutual attraction, and the whole chain of needles will form a single magnet, with a north pole at one end and a south pole at the other.

Fig. 156.

296. If we take a magnet of any shape and dip it into wrought-iron filings, we find that they adhere in large quantities to its ends or poles, but that very few adhere to any other part (fig. 156). This shows that the attractive force is much stronger at the ends than elsewhere.

297. Magnetic Induction.—In these clusters of filings which are lifted up by the magnet, each filing is a magnet, and hangs on to its neighbour by their mutual attraction, like the chain of needles in art. 295.

Fig. 157.

Instead of filings we may use a few short pieces of iron wire a quarter of an inch or half an inch long. If we hang one of them by its end from one pole of a magnet, a second may be hung from the lower end of the first, a third from the lower end of the second, and sometimes a fourth or fifth can be added, as shown in fig. 157. If we now take hold of the topmost piece and carefully detach it from the magnet, the other pieces, or

some of them, will remain supported for a little wh and will then drop off. As long as the chain ha together each of the pieces is a magnet; but their m netism is only temporary, and cannot long maintain it when the influencing magnet is removed.

298. If we try the same experiment with pieces of wire, we shall obtain an effect of the same kind, but two important differences—the effect is weaker for time, but more lasting. Steel, especially if of the har kind, when it has once been magnetized, retains its n netism with very little loss when left to itself; whe iron, especially if of the softest kind, can retain very l magnetism. The degree of hardness possessed by chiefly depends on the greater or less suddenness which it has been cooled. If plunged into cold w when at a bright red heat it becomes hard; if allowe cool gradually it becomes soft. Hard steel will scr soft steel, but is much more brittle. The hardnes softness of *iron* depends largely on its purity, perf pure iron being the softest and toughest of all.

299. The fact that the pieces of wire hang togeth a chain shows us that their contiguous ends are dissin poles. When a north pole of a magnet is presente one end of a piece of wire it makes this end of the a south pole. Whichever pole is presented, the near of the wire becomes a pole of the opposite kind, and h it is that they attract. Magnets attract iron becaus part of the iron that is nearest to either pole of a ma becomes for the time a pole of opposite kind, an therefore attracted. Some other part of the iron bec a pole of the same kind as the influencing pole, an therefore repelled; but, owing to the greater distance repulsion is weaker than the attraction, and hence the upon the whole is attracted. When a piece of iron is

across the poles of a horse-shoe magnet, the part which touches the north pole of the magnet is a south pole, and the part which touches the south pole is a north pole; there is accordingly attraction in both places.

The power which a magnet exercises upon pieces of iron in making them magnets for the time being is called *magnetic induction;* and the magnetism so produced in the iron is called *induced* magnetism.

300. Induced magnetism may coexist with permanent magnetism. This can be illustrated by gradually bringing a strong magnet near a compass-needle. When the magnet is not very near, each pole of the magnet is seen to repel one pole of the needle and attract the other, but at very small distances either pole of the magnet will attract either pole of the needle. In the latter case the induced magnetism in the needle is stronger than its permanent magnetism, and if we wish to avoid a permanent change in the magnetism of the needle we must perform the experiment cautiously, not bringing the magnet any nearer than is just sufficient to show the desired effect.

Chapter XXV.

LINES OF FILINGS. THE EARTH AS A MAGNET.

301. Very beautiful and instructive results are obtained by sifting wrought-iron filings over a flat sheet of card with a magnet underneath it, and then giving a few taps to the card or to the table on which the apparatus rests. The filings will arrange themselves in curves in a very singular manner. Fig. 158 shows the effect obtained with a bar-magnet laid flat; fig. 159 the effect with two bar-magnets laid in the same line at a little distance apart,

... one of these lines. The direction in which it ... as the direction of the magnetic force whic... in the place where the needle is set down.

Fig. 100

... set it down ov... middle of a b... net, as in fig. ... will point al... as shown in the figure, its south pole pointin... ... the magnet.

... is a great magnet; and we can t... ... the magnetic forces which it exert... ... the habitable globe by observin... ... points.

... along the earth's surface, always f... ... needle, the line which we trac... ... called a *magnetic meridian.* ... less from true north, and ... not exactly coincide wit... ... such as we see marked on n...

... meridians all meet in tw... ... so the magnetic m... ... the *north* and *south* ... poles have been actual... by navigators ... magnetic pole is a litt... north of ... North America, near t... where the remains of Sir John Franklin's expedit... found, and is about ... from the geographical no... The south magnetic pole lies to the south of Aus... distance of about ... from the geographic...

... If we lay a bar magnet flat upon a ta... ... compass over one of its ends, the needl... ... does not remain horizontal; one end di...

and the other tilts up. If we now hold the compass over the other end of the magnet, the end which was tilted up before will now dip down. If we support a needle on an axis running through its centre of gravity at right angles, fig. 163, it will place itself vertically when held over either pole of the bar-magnet, horizontally when held over the middle of the bar, and sloping when held over any other part of the bar. We can trace out, by the help of such a needle, the curved lines which represent the directions of the magnetic force at all points in the space over the magnet, and these lines will be almost exact copies of the lines formed by filings in the plane of the bar.

Fig. 163.—Dipping Needle.

305. The magnetic action exerted by the earth is nearly the same as would result from a very strong magnet placed at the earth's centre. The curved lines of force due to this magnet would, some of them, pass out through the earth's atmosphere; and a magnetic needle tends to set itself along one of these lines. The magnetic poles of the earth are the two points on the earth's surface which are opposite the ends of this central magnet; and the needle at these two places tends to set itself verti-

cally. Midway between them is a belt encirclin earth, and lying in a plane which would bisect the ce magnet at right angles. At places on this belt the n tends to set horizontally. This belt is called the *ma equator.* At all other places the needle tends to as a sloping position, and in Great Britain the slope is n 70°. This slope is called the *dip*, and in this part c world it is the north end that dips. At places o south side of the magnetic equator it is the soutl that dips. The dip is 0° at the magnetic equator, an at each magnetic pole; but the end of the needle v points down at one magnetic pole points up at other.

306. We are accustomed to call that end of the n which points to the north the *north* pole of the ne This is the end which dips in the northern hemisp It is therefore attracted by the northern end of the or the northern end of the central magnet. But which attract are unlike, and therefore the northern of the earth, or of the central magnet, is dissimilar t north pole of a needle.

307. At places where the dip is nearly 90°, the exerted upon the poles of a needle is nearly vertical its horizontal component is extremely small. At places a needle balanced on the same principle as a dinary compass-needle—that is, balanced so that it point horizontally, and can turn freely in a horiz plane—will exhibit a very feeble tendency to poin way more than another. Even in our own part o world the vertical magnetic force on the needle is r greater than the horizontal. This is at once seen by parallelogram of forces; for if we draw a line slopin 70° and complete the upright rectangle of which line is the diagonal, the height of this rectangle

be much greater than the base. The height represents the vertical magnetic force on one pole of a needle, the base the horizontal force, and the diagonal the total force.

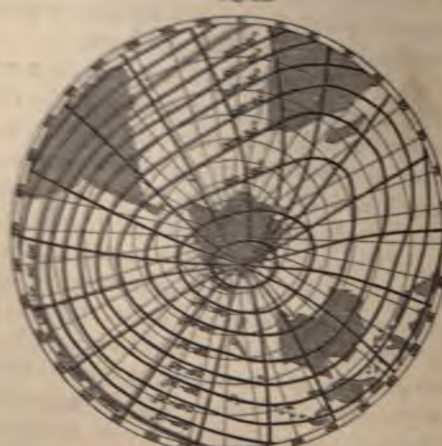
308. It is not easy to make experiments on dip, or on vertical force, without very well-constructed apparatus; for if the axis of suspension, about which the needle turns, does not pass accurately through the centre of gravity of the needle, the tendency of the centre of gravity to descend will conflict with the tendency to point in the direction of magnetic force, and the needle will assume an intermediate position.

309. Figs. 164, 165, which are taken from Airy's *Treatise on Magnetism*, are maps of the northern and southern hemispheres. The thin lines represent the geographical meridians (represented as straight lines), and the parallels of latitude (represented as circles). The thick lines represent the magnetic meridians meeting in the two magnetic poles A A, and a set of curves drawn through places at which the dip is the same.

310. Since a compass-needle points along the magnetic meridian, and a true north-and-south line is the same as the geographical meridian, the angle at which these two meridians cut one another is the difference between magnetic north and true north. In Great Britain the needle points nearly 20° to the west of true north. In some parts of the world it points to the east of true north. In some parts of the United States of America magnetic north and true north coincide, and this is also the case in some parts of Siberia and China. The difference between true and magnetic north is called by nautical men *magnetic variation*, and by scientific men generally *magnetic declination*. It is said to be westerly when magnetic north is to the west of true north.

Fig. [illegible]

Fig. [illegible]



Magnetic Meridians and Lines of Equal Dip.

311. The direction and intensity of the magnetic force at a given place do not remain always the same. In the first place they undergo periodical changes depending especially on the hour of the day. In the second place they occasionally undergo very violent fluctuations, which are called *magnetic storms*, and these are usually accompanied by the appearance of the *aurora borealis*. In the third place there are very slow changes going on from century to century. For example, about two hundred years ago the needle pointed due north in England, and previous to that time it pointed east of north.

312. Iron objects are acted upon inductively by terrestrial magnetism and made temporary magnets. If they remain for a long time in one position they usually acquire some permanent magnetism. A poker always kept in the same position when not in use will be found, in most cases, to have one end a permanent north and the other a permanent south pole. If the poker has been lying horizontally in the fender with one end to the north, this end will be the north pole. If it has been standing nearly upright the lower end will be the north pole. In both cases, if we compare the position of the poker with that of the dipping-needle, the end which points most like the north pole of the dipping-needle will be the north pole.

313. One of the ores of iron, called *magnetic oxide of iron*, is strongly affected by magnetism, though not so strongly as iron itself; and some specimens of it are permanent magnets. These latter are called **lodestones**.

In a later chapter we shall describe a method of making magnets by means of electric currents. More powerful magnets can be obtained by this means than in any other way.

314. By using exceedingly strong magnets, it can be

shown that all or nearly all substances are affected b
magnetism. Some, like iron, are attracted by a pole
a magnet, and others are repelled. Bismuth is a leadi
example of the latter class of bodies, nickel of the form
None of these bodies are affected near so powerfully
iron.

ELECTRICITY.

CHAPTER XXVI.

GENERAL PHENOMENA AND LAWS OF ELECTRO-STATICS.

315. Take a stick of sealing-wax, and rub it on the sleeve of a coat or any piece of cloth or flannel, after first drying the cloth at the fire. The wax will then exhibit attraction for small pieces of paper lying on the table; they will jump up and stick to it. The same experiment can be performed with a piece of rosin instead of sealing-wax, and the material called by the names of ebonite and vulcanite will answer still better. Glass may also be used, but more care is necessary in drying it, as the surface of glass has a great tendency to become coated with a thin film of moisture, which would prevent the experiment from succeeding. It is better to rub the glass, not with woollen cloth, but with silk, which must also be well dried by warming at the fire.

316. The attraction which these bodies, after being rubbed, are capable of exercising, is called *electrical* attraction, and the bodies themselves are said to be *charged with electricity.* We do not know what electricity is. It is believed not to be a substance. Perhaps it is some peculiar kind of motion. It is better for beginners not to speculate too much as to what it is, but to endeavour to familiarize themselves with its properties, which are very numerous and wonderful.

shown that all or nearly all substances are affected by magnetism. Some, like iron, are attracted by a pole of a magnet, and others are repelled. Bismuth is a leading example of the latter class of bodies, nickel of the former. None of these bodies are affected near so powerfully as iron.

kind of [illegible]
late too much [illegible]
liarize themselves [illegible]
merous and women [illegible]

317. Some substances, especially the metals, allow electricity to pass through them easily. They are called **conductors**. Some other substances, among which may be mentioned glass, sealing-wax, and indian-rubber, almost completely prevent it from passing. They are called **insulators**.

318. There are two opposite kinds of electricity, one of them called *positive* or *vitreous*, and the other *negative* or *resinous*. The electricity of rosin, sealing-wax, or vulcanite, when these substances have been rubbed on woollen cloth, is of the latter kind. The electricity of polished glass, when rubbed either with silk or wool, is of the former kind, and the name vitreous is derived from *vitrum*, the Latin word for glass. The two electricities are opposite, just in the same sense as the north pole of a magnet is opposite in kind to a south pole. Like poles repel one another and unlike attract; and just so, like electricities repel one another, and unlike attract.

When electricity is excited by rubbing two bodies together, one of them becomes positively and the other negatively electrified.

319. Lists of substances have been made out, arranged in order from positive to negative, so that when electricity is excited by rubbing any two of them together, the one which stands first of the two on the list will become positively and the other negatively electrified. The fur of the cat is generally placed at the head of the list, standing above glass, while glass stands above woollen stuffs, these again stand above silk, and silk above sealing-wax, rosin, shellac, and vulcanite. It is a singular fact that roughened glass stands very low on the list. It becomes negative when rubbed either with wool or silk.

320. The mutual repulsion of two similarly electrified

odies can be conveniently exhibited by taking a strip of ilk ribbon, doubling it so that the two ends come to-ether, and then stroking it briskly between the thumb nd finger of an indian-rubber glove. The strip being ung up by the middle, the ends will exhibit a strong endency to fly apart.

321. Pith-balls, on account of their lightness, are nuch used for showing electric attractions and repulsions. f we only want to show attraction, the ball may be ung by any kind of thread, and the effect will be stronger ith a cotton thread than with a silk one. If we want lso to show repulsion, the thread must be a good insulator, nd cotton will not do. Even silk does not always insu-ate, as the materials used for dyeing it or bleaching it ften give it conducting power. Raw silk, which has either been bleached nor dyed, is the best, and it should e dried at the fire just before using. When a pith-all is hung by an insulating thread of silk, the first ffect of a strongly electrified body held near it will be ttraction; but when it is allowed to touch this body, it enerally flies away and exhibits repulsion. The ex-lanation is that when it touches the body it takes to tself some of the electricity of the body, and then like epels like. The experiment sometimes fails, owing to eakage of electricity from the ball and suspending hread. To prevent leakage, the ball must have no oughnesses, and the thread must be a good insulator. When the ball retains its charge of electricity well enough o show good repulsion, a body electrified in the opposite vay may be brought near it. It will then be attracted y this body, though repelled by the other.

322. The experiment is most easily shown by using wo small Leyden jars with opposite charges, holding one ar in each hand, with their knobs near the insulated

pith-ball, on opposite sides of it. It will fly backv and forwards from one knob to the other with activity for a long time.

323. These experiments show that though ther resemblances between magnetic and electrical attract there are also great differences. A magnet doe first attract a piece of iron and then repel it, and a m does not lose any of its magnetism by being allowe touch bodies which it attracts; nor is any insulatio quired to prevent a magnet from losing its magnetiza

324. There is electric *induction*, just as there is netic induction; and it is owing to this induction an electrified body attracts pieces of paper lying table, or a pith-ball suspended by a conducting th The pith-ball is a conductor; and the electrified which is brought near attracts electricity of the opp kind to its own into the pith-ball, especially to the side, while electricity of the same kind as its ow repelled out of the pith-ball.

If the pith-ball is hung by an insulating thread attraction is less marked, for in this case the ball whole does not become charged with the opposite tricity. The further side of it becomes charged electricity similar to that of the influencing body, the near side with the dissimilar kind. Thus the side is attracted and the far side repelled, and the m of the ball as a whole results from the preponderan that force which acts at the smaller distance.

325. If two equal conductors are charged to ex the same strength with opposite electricities, and are allowed to touch one another, their charges will d pear. Positive and negative charges of electricity de one another. An uncharged conductor may thu regarded as containing equal charges of positive

negative electricity in unlimited quantity, ready to show themselves as soon as an influencing body is brought near.

No distinction can be made between taking one kind of electricity from a conductor, and giving it the other kind. To take positive electricity from an uncharged conductor is to give it a negative charge; and to take negative electricity from it is to give it a positive charge. To take equal quantities of both from it is to leave it still uncharged.

326. The power which an electrified body exercises, in causing its own kind of electricity to recede from the near side of a conductor presented to it, or, what amounts to the same thing, causing the opposite kind of electricity to come to this side, is called **induction**; and to distinguish it from magnetic induction which we have already described, as well as from some very different effects which we shall have to describe later in connection with electric currents, it is called **electro-static** induction.

327. The **gold-leaf electroscope** shown in fig. 166, is a convenient instrument for exhibiting the effects of induction.

Fig. 166.—Gold-leaf Electroscope.

The two gold leaves which are seen opened out in the figure are attached at their upper ends to a brass rod, which comes out at the top of the instrument and terminates in a knob. It is supported by the glass bell-

jar, which serves to insulate it from the earth. The upper part of the bell-glass is varnished, to prevent the deposition of moisture and preserve better insulation. The two rods with balls at their tops, standing up from the bottom of the jar, are brass rods in connection with the earth. They serve to increase the divergence of the leaves, and also to prevent the leaves from striking against the sides of the glass jar, which would be apt to cause adhesion. These two rods are not by any means a necessary part of the apparatus, and are very often dispensed with. The instrument generally requires to be warmed near the fire before using, but it does not need to be so thoroughly warmed and dried as bodies which are intended to be excited by friction.

328. When it is standing on the table ready for use, without any electrical charge, the two gold leaves hang down side by side, nearly touching each other. Now let an electrified body be held over the top, first at a considerable height, and gradually coming down nearer to the knob at the top of the instrument. The leaves will be seen to open out more and more, and care must be taken not to make them open out too suddenly or too far, as they are easily torn. They should not be made to separate further than is shown in the figure.

329. The explanation of their separation is, that the influencing body, which the operator holds over the top, repels electricity similar to its own into the leaves and lower part of the rod, while it attracts the opposite kind to the knob and upper part of the rod. The two leaves, being thus charged both with the same kind of electricity, repel each other.

330. The next step in the experiment is to touch the knob for an instant with the finger while the influencing body is still in its place over the top. The effect is to

make the leaves instantly collapse, and they remain collapsed if the influencing body is kept unmoved; but if it is either raised or lowered they begin to open out.

At the moment of touching, a portion of electricity (either positive or negative, as the case may be) has escaped through the body of the person touching to the earth, and the leaves are thus left without a charge. The knob, however, has a larger charge than it had before, and this (as before) is dissimilar to the charge of the influencing body.

If the influencing body is lowered, it repels some of its own kind of electricity into the leaves and increases the opposite charge possessed by the knob. If, on the other hand, it is raised, it allows some of the opposite electricity in the knob to go down into the leaves. The leaves will repel each other whenever they are charged with electricity, no matter of which kind. When the influencing body is removed altogether, the leaves will open out exactly to the width that they stood at before the knob was touched.

331. Having thus given the electroscope a charge, we can use it to test the charge of any other influencing body. If the body which we wish to test has a similar charge to that of the original influencing body, its effect when brought down over the electrometer from above will be to diminish the repulsion of the leaves, provided we do not bring it so close as to make them first collapse and then open out again. On the other hand, if it has an opposite charge to the original influencing body, its effect even from the first will be to increase the divergence of the leaves. It can easily be shown in this way that when a glass rod or a stick of sealing-wax is electrified by friction, the silk or flannel which served as rubber has a charge opposite to that of the glass or sealing-wax. In every mode of producing electricity, the rule is found to hold good that one kind is never produced alone, but an equal

if the finger or any other conductor connected with the earth is held within an inch or two of the prime conductor, a spark passes between them with a loud crack and a pricking sensation. The longest and loudest sparks are got by presenting a conductor terminating in a large knob. If we present a conductor terminating in a sharp point, there will be hardly any spark and no loud crack, but the electricity will pass across in a quiet and uniform manner like a steady stream instead of a succession of bursts.

340. This fact suggested to Franklin the idea of lightning-conductors. These are pointed rods of metal, which project above the top of the building they are intended to protect, and are connected by rods passing along the outside of the building with the earth. They have a twofold office: First, they discharge a steady stream of electricity from the earth into the air, when a thunder-cloud is passing overhead. This electricity is opposite in kind to that of the thunder-cloud, and tends to neutralize its influence. Secondly, when a flash of lightning occurs, it takes the easiest course to the earth, and thus passes through the conductor in preference to striking the building.

341. In fig. 168 a stool with glass legs is seen. If a person stands on this, and keeps one hand on the prime conductor while the machine is being turned, his body will become charged with electricity. No peculiar sensation is experienced until a conductor connected with the earth is brought near him, and then a spark passes between his body and this conductor. If a flat or rounded conductor connected with the earth is held over his head, his hair stands on end, and silent discharge takes place through the projecting hairs. If he holds his finger over the top of a gas-burner, a spark passes

across; and if the gas is turned on, the spark has sufficient heating power to ignite it.

342. We have described the frictional machine first, on account of its great historic interest, and because it is the most generally known; but stronger effects of the same kind can now be obtained, with much greater ease, by means of machines which work not by friction, but

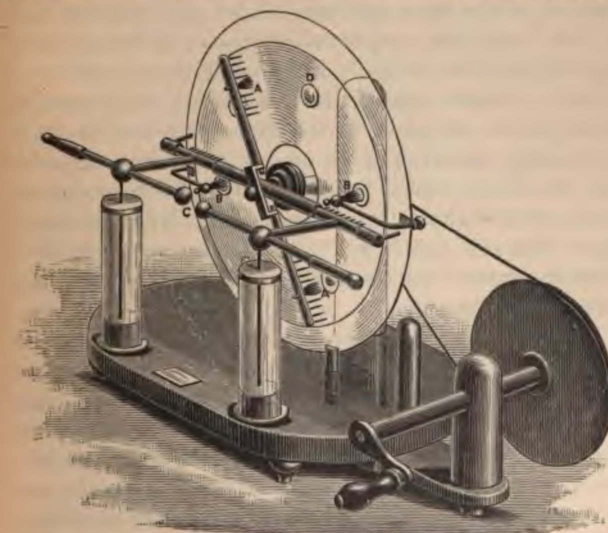


Fig. 169.—Voss Machine.

by electro-static induction. The best machine for most purposes is that known as Voss', being a modification of an earlier form invented by Holtz. Even the smallest size, with a revolving plate $10\frac{1}{2}$ inches in diameter, gives as powerful effects as a very large friction machine; and it is much easier to manage and keep in order. It is represented in fig. 169.

343. There are two glass plates, a small distance asunder. The larger one is fixed, and the smaller one is made to revolve rapidly by means of a driving band passing over two grooved wheels, one of them much larger than the other, the larger one being turned by hand. This plate has six metallic studs (like that at D) set in it at equal distances. The sloping bar which is seen in front of it is of brass, and carries two little brushes A A of thin brass wire, against which the studs rub as they pass by, and this happens at the same moment for both brushes. If we suppose that the fixed plate is charged with positive electricity in its upper part, and negative in its lower part, the upper stud will acquire a negative and the lower stud a positive charge, by induction, at the moment that the two contacts occur. When the studs have advanced about a quarter of a revolution, they come in contact with another pair of brushes B B which collect their charges.

These collecting brushes are in communication with two patches of tin-foil on the back of the fixed plate, which are not shown in the figure. Thus the right-hand patch will be continually replenished with negative, and the left-hand patch with positive electricity. This left-hand patch extends to the top of the fixed plate, and acts as the influencing body to draw negative electricity to the upper brush and stud. The right-hand patch in like manner extends to the bottom, and attracts positive to the lower stud.

344. The action which we have described produces rapid increase of any slight charges that the two patches of tin-foil may possess at starting: and when the machine is dry there is generally a sufficient trace of electricity remaining in it to furnish a basis for this rapid process of multiplication. In unfavourable weather it may be

necessary at the outset to employ a flat piece of vulcanite (or other suitable substance), which has been electrified by friction, and hold it at the back of the fixed plate opposite the highest or lowest brush, till the machine begins to work.

345. When the two patches of tin-foil have acquired their charges, a great deal more electricity is produced than is necessary for keeping them up. The surplus is collected from the revolving plate by rows of brass points, just as in the friction machine. They are ranged along the two horizontal radii of the plate, one row collecting positive and the other negative. They are in connection with the two knobs C which are seen in front of the machine, and a brilliant discharge of electricity takes place between these knobs. In the above description we have supposed the right-hand patch of tin-foil to be negative. It will accordingly attract positive electricity from the right-hand conductor to the points, through which the positive electricity will stream off on to the face of the plate, leaving the conductor with a strong negative charge. The right-hand knob will therefore be negative, and the left-hand knob positive. The knobs are at the ends of sliding rods with insulating handles, and can either be placed in contact or separated to any distance not exceeding 5 or 6 inches. They should be about half an inch apart at starting, and be gradually opened wider as the discharge becomes stronger.

346. The **Leyden jar** is an instrument which is useful for collecting a large quantity of electricity in small compass.

The essential parts of it are, two conducting surfaces at a small distance apart, with glass or some other good insulator between them. It usually consists of a glass jar, lined with tin-foil both inside and out, with the ex-

... upper part, which is ... ... a knob is fastened ... connection with the ...

... exhibit any peculiar ... are given to its ... allowing the outer coating ...

... a charge is given to ... The charge, as fa... ... electricity of ... outer coating; ... glass just as ...

... jar, it is usual ... *discharger*, wh... ... of a jointed br... ... with a glass handle ... be pressed against

outer coating, and then the other knob must be brought close to the knob of the jar. Before it has quite touched, a bright spark passes across with a loud report.

348. A shock can be obtained by first putting one hand on the outer coating and then touching the knob with the other hand, or a weaker shock can be obtained by simply touching the knob. In the first case the electricities run from one coating to the other through the arms and chest, in the second case through one arm and the body and through the soles of the boots. A number of persons may obtain a shock together by taking hold of hands so as to form a chain. The person at one end of the chain must lay his hand on the outer coating of the jar, and keep it there till the person at the other end touches the knob, when all will feel the shock at the same instant.

349. The peculiar power which a Leyden jar possesses of holding a large charge depends on the attraction which takes place between the two opposite electricities on its two coatings. The thinner the glass is, the nearer will these two opposite electricities be to one another, and the more strongly will they attract each other. Hence a jar of thin glass will hold a larger charge than one of the same size of thick glass.

If a Leyden jar is hung by its knob from the conductor of a machine, leaving the outer coating insulated, the jar cannot be charged. One coating cannot receive its charge unless the other coating has the opportunity of receiving an opposite charge.

In like manner, when the jar has been charged, it cannot be discharged by touching one coating while the other coating is insulated. Let a strongly-charged jar be set upon a stool with glass legs. By touching its knob we shall obtain a small spark; then by touching its outer

coating we shall obtain a second spark if the
is good. We may go on touching the insi
coating alternately dozens of times, getting
spark every time, and there will still be enoug
left to give a powerful discharge when the
are connected.

350. Any instrument constructed on the p
the Leyden jar is called a **condenser.** Fig. 171
Volta's condensing electroscope, which differs

Fig. 171.—Condensing Electroscope.

ordinary gold
troscope in
stead of a k
plate of br
second brass p
a glass han
either be plac
first or lifted
faces of the br
must be cover
an insulating
which prevent
from touching,
swers the same p
as the glass of a L
jar. The backs
two plates shou
left unvarnished. Suppose we begin by removing the u
plate and giving the electroscope a charge in the ordi
way; then bring the upper plate over the top at a mode
distance. We shall not see much effect if we hold it
the time by the glass handle, but if we hold it by
brass so as to keep it connected with the earth it w
exhibit a powerful tendency to make the gold leaves
together, and when it is set down on the lower plate th

not exhibit any repulsion at all. This is
rly all the electricity goes from the leaves to
late, in obedience to the attraction of the
ctricity of the upper plate, which has come to
earth. While the plates are approaching
each is receiving more and more electricity
nce of the attraction of the other, one getting
rom the earth and the other from the gold
hen the upper plate is lifted off again, the
each other just as vigorously as before.

have a large conductor with too feeble a
fect an ordinary electroscope, we may connect
of the two plates of the condensing electro-
ect the other plate for a moment with the
disconnect the conductor, and finally lift off
late, when the leaves will probably be seen to
y proceeding in this way we give the leaves a
aps a hundred times as strong as they could
ed without the use of the condensing arrange-

her example of
ondensation is
the electro-
172). This in-
onsists of two
wer one of vul-
ellac, with tin-
ottom, and the
f brass, with a
e. We begin
friction with

Fig. 172.—Electrophorus.

r flannel to the upper surface of the lower
thus acquires a negative charge. We then
per plate upon it and press it closely down.

In this process, the upper plate, being in connection with the earth, acquires a positive charge by induction; and if we now lift off the upper plate by its glass handle we can get a good spark from it. We may then press it down again, remove it again, and get another spark, and so on, time after time. If the insulation is thoroughly good, hundreds of sparks can be drawn in this way without the necessity for renewing the charge on the surface of the lower plate.

It might have been expected that the upper plate would require a coating of varnish to prevent it from touching the lower one; but experience shows that a smooth plate of metal does not easily receive electricity

Fig. 173.—Leyden Battery.

from an insulating substance. The tin-foil at the bottom is useful in helping the lower plate to retain its charge when the upper plate is lifted off.

352. Leyden jars are sometimes combined together to form a Leyden battery, as represented in fig. 173. Their

inner coatings are connected together by brass rods, and their outer coatings are connected with each other and with the earth by means of a tin-foil lining to the box, which is in connection with the chain shown in the figure. The chain should be connected with the negative conductor of the charging machine, and the inner coatings with the positive conductor, if it is desired to give the inner coatings a positive charge. The battery can be discharged by connecting any one of the outer coatings with any one of the knobs by means of the jointed discharger; or if the Holtz machine or Voss machine is used, the sliding knobs of the machine may be placed at such a distance (1 inch or so) that the discharges will take place of themselves as we go on working the machine. Great care must be taken not to get a shock, as it is extremely dangerous.

The arrangement shown at E is called a **quadrant electroscope**, and is intended to show whether the battery is strongly charged. It consists of a pith-ball hanging by a straw which can swing freely, and as the charge increases the ball is repelled outwards from the upright stem. There is a graduated card behind the straw for indicating the angle of deflection. A similar instrument is often attached to the prime conductor of an electrical machine, as in fig. 168.

ELECTRIC CURRENTS.

CHAPTER XXVIII.

GALVANIC BATTERIES AND THEIR EFFECTS

353. Every discharge of electricity may be regarded as an electric current; but we are now going to consider methods by which a steady electric current may be maintained for a long time. Such a current bears the same relation to the discharge of a Leyden jar as a steady pressure does to a violent blow. All that we have said about the distinction of *positive* and *negative* in connection with the flow of electricity from one part of a conductor to another is equally true for these steady currents. A current of positive electricity flowing in one direction is to be regarded as the same thing as a current of negative electricity flowing in the opposite direction; so that if one person says that a positive current is flowing down a wire and another person says that a negative current is flowing up it, they are merely stating the same fact in different words.

It is customary, for the sake of brevity, to designate the positive current as "the current," so that when we say "the current is flowing down" a wire the meaning is that positive electricity is flowing down it, or, what is the same thing, negative electricity is flowing up it.

354. The easiest way to produce a steady current is by means of a **galvanic cell,** or a combination of such cells called a **galvanic battery.** In a galvanic cell, chemical

action takes place between a liquid and a metal—usually zinc—which is partially immersed in it; and there is another metal, or solid conducting substance of some kind, also partially immersed. The zinc and the other solid conductor are called the two *plates* of the cell. The plates must not be allowed to touch each other in the liquid; but when we want to get a current we must connect them outside the liquid. This might be done by letting them touch outside the liquid; but it is more usual to connect them by a wire, or rather by two wires fastened one to each plate by screw clamps or binding-screws. The current will flow as long as these wires are in contact, and will cease flowing when they are separated. It flows from the inactive plate through the wires to the zinc plate, and completes its circuit by flowing from the zinc plate through the liquid to the inactive plate. There is a continual cir-

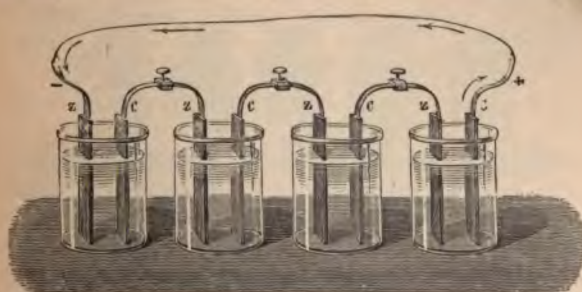


Fig. 174.

culation of positive electricity in this direction round the circuit as long as the chemical action continues, or, what is the same thing, there is a continual circulation of negative electricity in the opposite direction.

355. The inactive plate is usually either of copper, of platinum, or of gas-carbon, that is, the carbon which is

[illegible]

Fig. [illegible] represents a very common [illegible] tery called **Bunsen's**. The zinc plate consist[illegible] cylinder surrounding the porous vessel in [illegible]

Fig. [illegible].—Bunsen's Battery.

carbon plate stands, the whole being contained in a [illegible] vessel. The liquid in which the zinc is immer[illegible] dilute sulphuric acid, and the liquid in the porous [illegible] strong nitric acid.

Fig. [illegible] represents a **Daniell's cell**, which differs [illegible] Bunsen's in the contents of the porous cell. The [illegible] within the porous cell is of copper, and the liquid [illegible] contact with the copper is a saturated solution of sulph[illegible] of copper, crystals of which are seen heaped up rou[illegible]

These crystals are supported by a cage of copper are intended to keep the solution saturated.

e most convenient cells for most class experi- the bichromate of potash **bottle-cells**, one of epresented in fig. 177. The liquid is a solution of bichromate of potash, with a little sul-phuric acid added. In this liquid two flat plates of car-bon are sus-pended, and between them is a flat plate of zinc, which can be slid up and down by a rod projecting through f the cell. It is slid up in use, and is then just clear of the liquid. By down (which can be done instantaneously), the ought into full action, and as soon as the ex- is concluded the zinc should again be raised out uid. The cell is not suited for long-continued such purposes Bunsen's is much better; but ery powerful effects when only used for a few t a time. It has the conveniences of great and of freedom from noxious fumes.

aniell's Cell.

Fig. 177.—Bichromate Bottle-cell.

ll give some further explanation of the action es later on, when we come to speak of *electro-* e shall now describe some of the effects which uce.

338. [illegible] effects is the production of heat [illegible] some of the very finest iron [illegible] obtained—the refuse sold [illegible] perfectly well: it is about the thick- [illegible] An inch or so of this wire is [illegible] melted by sending through it the [illegible] three or four good cells. A [illegible] heated only red-hot, or to a still [illegible] The longer the wire is, and the [illegible] difficult it will be to raise to a [illegible] wire is much more difficult to [illegible] conducts too well; platinum is [illegible] iron, and can be raised to a [illegible] melting.

[illegible] are often exploded by having a [illegible] them, which is connected, at [illegible] wires leading to a place [illegible] battery, by means of which [illegible] and raise the wire to a [illegible] the explosion almost at the [illegible] with the battery.

[illegible] various forms, is another [illegible] of a current, as we shall [illegible]

339. [illegible] exhibited by a current is the [illegible] needle.

[illegible] employ an ordinary mariner's [illegible] a compass needle, supported [illegible] is more convenient. The [illegible] the current is flowing should run [illegible] and should be brought down over the [illegible] cause the needle to turn away from the [illegible] meridian, and to remain deflected as long as [illegible] (with the current flowing through it) remains in

the same position. If the current is flowing from south to north, the north end of the needle is deflected to the west, and the south end to the east. We can tell which way the current is flowing in a wire by means of this test; for if the current is reversed the deflection is reversed.

We shall also obtain deflection by making the current flow below the needle instead of above it. A current from south to north belów the needle will deflect the north end to the east. In both cases the current would make the needle stand at right angles to the direction of the wire, were it not for the magnetic action of the earth which tends to keep it north and south.

360. By experimenting with a wire and a needle in various positions, and bringing the wire sometimes close to one pole and sometimes close to the other, we find that the wire exerts a sideways thrust upon each pole, not a direct push or pull, and always in accordance with the following rule:—

Fig. 178.

Fig. 179.

Ampère's Rule.

Suppose yourself in the place of the wire, with the current entering at your feet and coming out at your head, while your face is turned toward the needle. Then the north pole will be deflected to your left and the south pole to your right. The north pole receives a push as if you stretched out your hand and pushed it

361. [illegible]

362. [illegible] ... on the further side, the ... to your left.

363. A piece of iron with wire wound round it for the purpose of magnetizing it by means of a current, is an electro-magnet. The wire is usually covered with gutta-percha, or silk, or cotton, so as to preven[t the] current from leaking across, and compel it to [flow] through the whole length of the wire.

The horse-shoe form is frequently employed, as i[n Fig.] 190, and the middle portion of the bar is often left

as here represented. The current is supposed to flow from the end of the wire marked + to the end marked −. If we imagine the bar straightened out by raising both ends, the current will be *descending* on the near side in both portions. The left-hand end is accordingly a *south* pole, and the right-hand end is the north pole.

Fig. 180.—Horse-shoe Electro-magnet

364. Another common arrangement is shown in fig. 181. It consists of two straight electro-magnets E E′ side by side, with their poles pointing opposite ways, so that the two poles at the same end are dissimilar. The dissimilar poles at one end (the right-hand end in the figure), are connected by a short bar of iron, which is

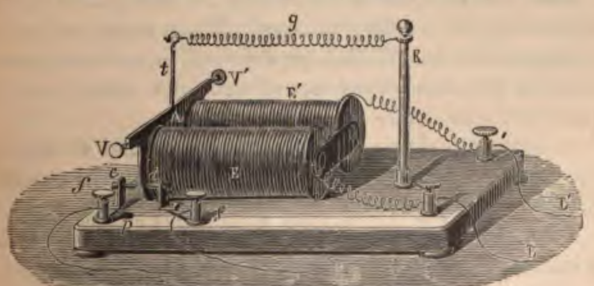


Fig. 181.—Electro-magnet with Opposing Spring.

equivalent to the uncovered part of the horse-shoe in fig. 180. At the other end there is a piece of iron A (called an *armature*), which can turn round an axis V V′; and a spring g is constantly pulling at the end of the arm t, thus tending to draw the armature away from the electro-

magnet. When the current passes, the electro-magnet overcomes the resistance of this spring and draws the armature to itself, but as soon as the current stops the armature flies back. This plan is very much used for electric telegraphs. The two screws *c* and *d* are so adjusted that the armature is never allowed to come quite up to the electro-magnet, but is arrested by coming in contact with the end of *d*, while in the return it is in like manner arrested by *c*. These two stops are usually set so near together that the play allowed to the armature is very small. This renders the action quicker, which is very desirable in telegraphy. L and L′ are the wires by which the current enters and leaves the electro-magnets; and it is no matter in which direction the current passes, the effect on the motion of the armature being precisely the same whether the current flows from L to L′ or from L′ to L.

365. The iron bar round which the coil passes in an electro-magnet is called the *core*. When rapid magnetization and demagnetization are required, it is advantageous to make the core consist not of one solid piece but of a bundle of iron wires.

It is very common to speak of *making* and *unmaking* an electro-magnet. It is *made* by sending a current through the coil, and *unmade* by stopping the current.

Electro-magnets are usually very much stronger than permanent steel magnets of the same size.

CHAPTER XXIX.

ELECTRO-CHEMISTRY. ELECTROMOTIVE FORCE RESISTANCE.

366. We now come to the *chemical effects* of electric currents, and these are closely connected with the action which takes place in the galvanic battery itself. The current is produced by allowing an acid to unite with a metal in the cells of the battery; and the current, in its turn, is able to separate an acid from a metal. For example, if we dissolve the blue crystals which are called *blue vitriol* or *sulphate of copper*, in water, thus making a solution of sulphate of copper, and then dip into the solution two wires connected with the first and last plates of a battery (called the *poles* of the battery), the acid will come to the wire connected with the positive pole (carbon or copper), and the copper will go to the wire connected with the negative pole (zinc). If we keep the wires immersed for some time, we shall find that the positive wire is being eaten away and the negative wire is gaining in thickness.

367. If we dip the two wires into water containing a little sulphuric acid, oxygen comes to the positive wire and hydrogen to the negative. The hydrogen is given off from the negative wire in small bubbles. The appearance at the positive wire will depend on what the wire is made of. If it is copper, it is oxidized, and nothing very noticeable is seen; but if it is platinum, the oxygen, instead of uniting with it, comes away in bubbles. The bubbles of oxygen and of hydrogen can be collected either separately or together; and in the latter case, if the mixture be fired (which is usually done by an electric spark), it goes off with an explosion and turns to water. The

process of collecting them separately is shown in fig. 18
The two wires from the battery are connected to tw
strips of platinum, over which are placed two invert
tubes completely filled with acidulated water simil
to that contained in the vessel. The bubbles of g
which come off from the strips rise through the liqui

Fig. 182.—Voltameter.

and the two gases thus accumulate in the upper part
the tubes, the hydrogen occupying double the volume
the oxygen. An apparatus of this kind is called a vol
meter, and it may be used for measuring the quantity
electricity that passes in a given time, for the quantity
electricity that passes is exactly proportional to the qu
tity of gas given off.

388. The separation of two constituents of a chemi
compound by means of an electric current is called el
trolysis. It has received several important indust
applications. Fig. 183 represents an apparatus for elect
gilding. A solution containing gold in union with cert
other substances is contained in a large vessel, on the

of which rest two stout copper rods. From one of these is hung a plate of gold, and from the other the articles of baser metal which are to be gilded. The two rods are then connected with the terminals of a cell, in such a manner that the current passes from the gold plate through the liquid to the articles which are to be gilded. Acid

Fig. 183.—Apparatus for Electro-gilding.

is separated from the solution at the surface of the gold plate, which it gradually dissolves, while gold is separated from the solution at the surface of the articles which are to be gilded, and forms a permanent coating. Electro-plating is performed in a similar manner. It is necessary that the surfaces which are to be coated should be thoroughly cleansed from grease, otherwise the coating would not adhere.

369. Electrotype is a process for obtaining copies of the form of a surface by means of electricity. The copies are usually of copper, and this is deposited on a mould taken from the surface which it is desired to reproduce. If it were taken direct from the surface itself, it would be convex where it ought to be concave, and *vice versâ*. If the mould is of non-conducting material, it is rubbed over

... to give it a conducting surface. ... the arrangements are of the same ... the liquid in the bath ... of copper, and a copper plate ... connection with the positive terminal.

... the most important applications of electro... reproduction of wood cuts and pages of type ... This book is printed from electrotypes.

... application of electrolysis is the ... of purity. A current sent through ... with ordinary commercial copper ... of extreme purity, and this is ... wires.

... in which electrolysis is going on is an electrolytic cell, and there is a very close relation ... on one of these cells and the action in ... the battery; for instance, if the ... water, the weight of water that is ... and hydrogen is $\frac{1}{65}$ of the weight ... one cell of the battery ... copper, as in the process of electro... weight of copper deposited is ... dissolved in any one cell of the ... a Daniell's, in which copper is ... on the copper plate while the ... rule is applicable to the deposit ... battery itself.

... of a battery is sent through a series ... the above rules will still be applicable ... The quantity of copper deposited in a cell ... of the quantity of electricity that has ... the cell, quite irrespective of how many ... are connected with it.

... The number of electrolytic cells that can be

worked in a series by a given battery depends upon what is called the **electromotive force** of the battery.

To take the simplest case, suppose that we have a number of battery cells all alike, but that, instead of joining them up in the proper way, as shown in fig. 175, we reverse the connections of a few of them; the current in these reversed cells will flow through the liquid from carbon to zinc instead of from zinc to carbon, and the reversed cells will be electrolytic cells. Instead of zinc being dissolved in them zinc will be deposited in them, and there will be just as much zinc deposited in one of these as is dissolved in one of the direct cells.

If the cells are all alike, the number of electrolytic cells must be less than the number of direct cells. If the numbers are exactly equal no current will pass either way, and if we reverse a majority of the cells the current itself will be reversed with them.

If the numbers are nearly equal, the current will be very weak and the action in each cell very slow.

372. The statements which we have made as to the quantity of zinc dissolved in each cell of a battery when electrolysis is going on, are on the supposition that the battery is in proper working order. Sometimes there is a wasteful action which we have taken no account of, due to impurities in the zinc plates which give rise to local currents between one point of the plate and another. These local currents complete their circuits in the individual cells, and contribute nothing to the general current. The evil can be remedied by rubbing the zinc plates with mercury so as to give them a coating of amalgam.

373. Whenever chemical combination takes place heat is produced; but in the ordinary use of a galvanic battery only a portion of this heat is produced in the cells themselves; the rest of it is produced in the external con-

[illegible] completes the circuit. When we heat a wire [illegible] the current through it, the heat that [illegible] a portion of the heat due to the chemical [illegible].

[illegible] electrolytic cells in the circuit of a [illegible] decomposition in these produces cold or uses [illegible] less heat for raising the tempera[illegible].

[illegible] purposes of electrotype and electroplating, the [illegible] the circuit represents so much energy [illegible] be made as small as possible. To this [illegible] battery cells employed should be the [illegible] give any current at all through the [illegible].

874. [illegible] about electrolysis will assist the [illegible] what is meant by *electromotive force.* [illegible] of a battery, these cells [illegible] to the other cells, [illegible] the direction of the greater of [illegible] forces. If we have two [illegible] a set of Daniell's and a set of Bun[illegible] electromotive forces by [illegible] are able to force a current [illegible] other sort. If the current [illegible] Daniell's to 5 Bunsen's, [illegible] we increase the Daniell's from [illegible] that the electromotive force of a [illegible] of that of a Bunsen.

875. [illegible] what is meant by electrical resistance. A battery gives a stronger current when its terminals are connected by a short thick wire than when this is taken away and a long thin one substituted. The long thin one has greater resistance. Two wires are said to have the same resistance if the substitution of

one for the other makes no difference in the current. A long wire has greater resistance than a short one of the same kind, the resistance being in direct proportion to the length; and a thin one has greater resistance than a thick one, the resistance being in inverse proportion to the sectional area or to the square of the diameter. Thus if we quadruple the length and double the diameter, the resistance will be unchanged; but if we double both the length and diameter the resistance will be halved.

The material of the wire must also be taken into account; a *good conductor* is another name for a substance of small resistance, and a *good insulator* is a substance of enormously great resistance. Pure copper conducts about 6 times as well as pure iron; in other words the *specific resistance* of iron is about 6 times that of copper. Hence a copper wire must be 6 times as long as an iron wire of the same diameter, if it is to have the same resistance. Resistance is affected by temperature. Metals conduct best when cold, but carbon conducts best when hot.

376. The current of a battery has to make its way against the resistance of the whole circuit, and this includes not only the wire which connects the terminals, but also the plates and the liquids in the cells. The resistance of the plates is comparatively small, but the resistance of the liquids often constitutes a large part of the whole resistance of the circuit.

It is advantageous to have the two plates in a cell near together; for this diminishes the resistance by shortening the liquid conductor along which the current has to flow. It is also advantageous to have plates of large area; for this diminishes the resistance by virtually increasing the sectional area of the liquid conductor. The electromotive force is not affected either by the size of the plates or by their distance; when a large cell

be opposed to a small one of the same kind, no current passes either way.

377. The quantities of heat generated by a current in the different parts of a circuit are proportional to their resistances; so that, if we have two stout copper wires coming from the terminals of a battery, and we connect them by a copper wire of half the diameter, or one-fourth of the section, there will be four times as much heat generated in an inch of this wire as in an inch of the stout ones; and as there is only one-fourth of the substance, it will rise in temperature about 16 times as fast, until it becomes so hot that the radiation of heat from its surface nearly balances the supply.

378. The strength of the current (or the quantity of electricity that passes in a given time) would be doubled if we doubled the electromotive force without altering the resistance, and would be halved if we doubled the resistance without altering the electromotive force. Doubling the number of cells doubles the electromotive force, but it also doubles the resistance of one part of the circuit, namely the part consisting of the battery itself, the resistance of the other part—the connecting wire—remains unaltered, the whole resistance is therefore increased, but not doubled. If the resistance of the connecting wire is many times greater than that of the battery, the whole resistance will not be much altered and the current will be nearly doubled. If the resistance of the connecting wire is very small compared with that of the battery, the whole resistance will be nearly doubled, and the current will scarcely be increased at all.

CHAPTER XXX.

GALVANOMETER. THERMO-ELECTRICITY.

379. We have mentioned several effects of currents; and as all of these effects increase when the current increases, any one of them might be made to serve as an indicator of the strength of the current. The effect that furnishes the handiest means of measurement, and is most frequently employed, is the deflection of a magnetic needle. Instruments for measuring the current by this means are called **galvanometers.** They contain a coil of wire for the current to pass through, and a magnetic needle, which, in the simplest kinds, is placed in the centre of the coil.

380. A very rough and early form of this instrument is shown in fig. 184. The coil must be in a vertical plane, and must be placed in the magnetic meridian; in other words, it must be placed so that when no current is passing, the needle is in the plane of the coil. When a current is sent through the coil, the needle will be deflected one way or the other according to the direction of the current. In the figure, the northern half of the needle is shown dark, and the southern half light. If the current is ascending in the near end of the coil (the south end), it passes over the needle from south to north, descends at the north end, and returns from north to south below the needle. In each of the four parts of

Fig. 184.—Schweigger's Multiplier.

this course it urges the north end of the needle towards the west, and the south end towards the east. This is true for each separate convolution of the coil, and the forces produced by the different convolutions are all added together; so that 20 convolutions will produce the same effect as a single convolution would produce with a current 20 times as strong. (Hence the old name *multiplier*.)

381. A more elaborate form of galvanometer is exhibited in fig. 185. The coil here is circular (its plane being vertical as before), and a graduated horizontal circle is provided for reading off the angular deflection of the needle. There is also an arrangement for turning the coil round a vertical axis, and a graduated circle for showing how far it has been turned, the intention being that it should be turned till it overtakes the deflected needle. This last arrangement is not often employed, the coil being usually kept in the plane of the magnetic meridian.

Fig. 185.—Galvanometer.

From observing either the deflection of the needle or the angle through which the coil must be turned to overtake the needle, in an instrument of this kind, the strength of the current can be computed with the help of Trigonometrical Tables.

382. Another kind of galvanometer which is very much used is shown in fig. 186. Its needle is double, consist-

of two needles, as nearly alike as possible, fastened he same upright stem, with their poles turned oppo-

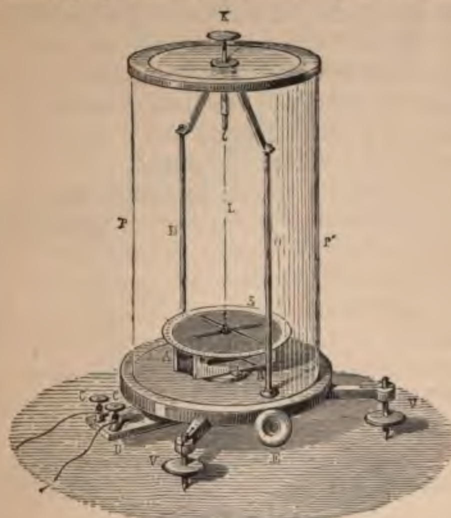


Fig. 186.—Astatic Galvanometer.

ways. As far as the influence of the earth's mag- ism upon them is concerned, they behave like a single dle very feebly magnetized, the two needles tend to turn osite ways; but they are so ced with respect to the coil t the current tends to turn m both the same way. This xplained by fig. 187, which ws the two needles and one volution of the coil.

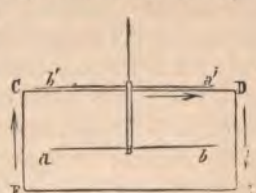


Fig. 187.—Astatic Needle.

The lower needle is in the centre of the coil, as in the vanometer already explained, and all parts of the coil

[illegible] deflected as long as the junction is maintain[ed at this] temperature, showing that the current conti[nues]. Now remove the source of heat and leav[e the junction to itself]: the needle will gradually retu[rn], showing that the current gradually dies away. [If we] warm the other junction, leaving the first cool, and [the needle will be] deflected in the opposite direction, sho[wing] that the current is reversed.

385. After the experiment has been shown in a [satis]factory way with moderate warming, we may heat o[ne of] the junctions till it is so hot that it would bliste[r the] finger. This will cause a large deflection; but, stran[ge to] say, if we make it still hotter, the deflection diminish[es] [illegible], and then is reversed, so that at a red hea[t we] shall have a very large reverse deflection.

Currents obtained in this way are called **the[rmo]-electric**, and any two metals will serve. Two m[etals] very frequently used for the purpose are bismuth [and antimony].

386. [The] effect can be increased by joining a nu[mber of bars] of the two metals in alternate successio[n, as] shown in fig. [illegible] If we warm the [row] of junctions w[hich] lie at the top i[n the] figure, the cu[rrent] will be in one d[irec]tion, and if we w[arm] the junctions w[hich lie] at the bottom it will be in the opposite direction. [With bi]smuth and antimony the rule is, that the current [flows] from bismuth to antimony through the warm junct[ion], and from antimony to bismuth through the cold [junc]tions.

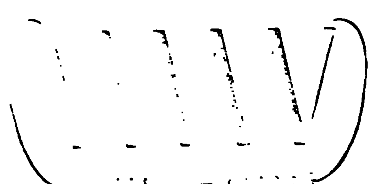


Fig. [illegible] Thermo-electric Chain.

387. We cannot get thermo-electric currents without differences of temperature. If all the junctions were warmed up to the same point we should have no current at all. Again, it is not material whether the two metals are in direct contact or have a third metal between them; hence there is no objection to their being soldered together at the junctions.

By increasing the number of junctions we multiply the electro-motive force in the same proportion, but the whole electro-motive force is generally very small. With copper and iron it would require about 2000 junctions, one half of them at 0° C. and the other half at 100° C., to give the same electro-motive force as an average battery cell.

388. The chief use that has been made of thermo-electricity is the construction of an instrument which takes the place of a thermometer and answers better than a thermometer for some purposes. It is called the **thermo-pile**, and is represented in figs. 191 and 192.

Fig. 191

A number of bars of bismuth and antimony are built up into a form something like a cube, as shown in fig. 191. Each bar is soldered at one end to one bar and at the other end to another bar, in such an order that they form a series in which the two metals occur alternately. The first and last bar in the series are only soldered at one end, and these two bars are connected with the two binding-screws, which are shown projecting from the sides, with wires attached, in fig. 192.

Insulating varnish is placed between the bars, so that the current cannot leak across, but must traverse the whole length of the chain and pass through all the junctions. The cube of bars is mounted in a case, which can be left open at the ends, thus exposing all the junctions. The

thermopile is usually employed in connection with tatic galvanometer, as shown in the figure. If bot of the pile are at the same temperature there is n

Fig. 192.—Thermopile with Galvanometer.

rent, but a very small difference of temperature s to give a sensible deflection of the needle.

The apparatus has been especially employed f searches on radiant heat, and one end is generally co with lamp-black varnish to make it receive and gi radiant heat more quickly.

Chapter XXXI.—MAGNETO-ELECTRIC CURR

339. We now come to a more important source o tric currents—the most important source of all— **neto-electricity.**

Take a horse-shoe electro-magnet, like that in fig and connect the two terminals of its coil with the ter

of a galvanometer at a distance of several feet; then take a powerful steel horse-shoe magnet, and bring its poles into contact with those of the electro-magnet. This will produce an instantaneous current in the coil of the electro-magnet, which will be shown by a considerable deflection of the needle; but if the poles are left in contact the current does not continue. Now pull away the steel magnet, and an instantaneous current will flow in the opposite direction. The iron core of the electro-magnet is magnetized by touching the steel magnet, and loses its magnetism when they are separated. The experiment accordingly shows that currents are produced in the coil of an electro-magnet by magnetizing and demagnetizing its core. The currents produced are so strong that, if a delicate galvanometer is employed, it is not safe to let the magnets touch—a piece of card must be interposed, or injury will be done to the galvanometer.

390. Another way of producing a current in a coil is to thrust a magnet into the interior of the coil, as represented in fig. 193.

Fig. 193.—Current induced by Motion of Magnet.

Generally speaking, any movement of a magnet in the neighbourhood of a coil of wire produces a current in the coil; and the same effect will be obtained if the magnet is stationary and the coil is moved. It is only the relative movement that counts.

The quicker the motion is the stronger the current is; but it lasts a shorter time, and no more electricity passes when the motion is rapid than when it is slow; it only passes more quickly.

Currents produced in this way are said to be *induced*, and the process is called **magneto-electric induction.**

391. Fig. 194 represents a very common but rather old-fashioned form of magneto-electric machine. Some parts are shown on a larger scale in fig. 195. An electro-magnet (shown in both figures), consisting of two coils with their cores connected at the back by a flat bar of iron, can be made to revolve rapidly near the poles of a steel horse-shoe magnet. If we start with the two cores immediately opposite the poles of the steel magnet, a current is

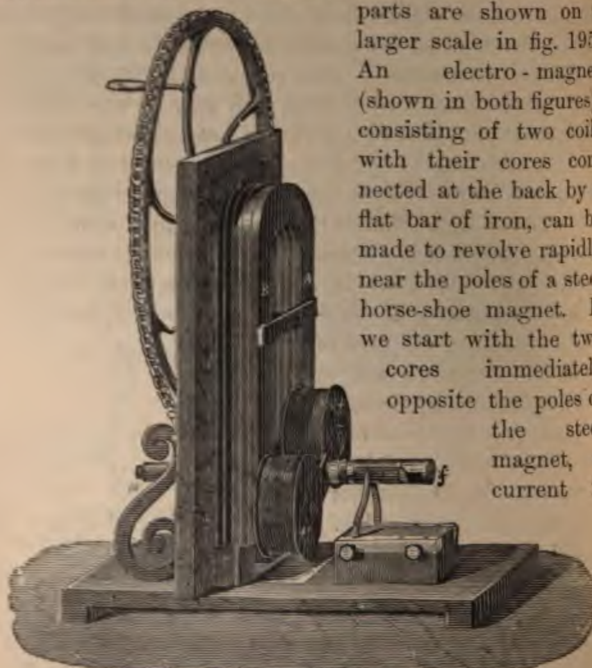


Fig. 194.—Clarke's Machine.

induced while they are moving round from this position to the exactly opposite position. During the first half of this movement the cores are losing their magnetism, and during the second half of it they are acquiring opposite magnetism to what they had before. The current is in one direction all this time, and during

the next half revolution, which brings them back into their original position, there is a current in the opposite direction. There are thus two currents in opposite directions in each revolution, and the reversals take place at the moment of passing the poles.

392. Fig. 195 shows the arrangements for leading off these currents into an external circuit.

N and N′ are the binding-screws for attaching the external wires; *r* and *r′* are two springs connected with

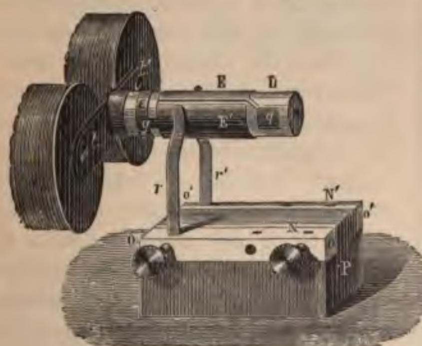


Fig. 195.—Commutator of Clarke's Machine.

these binding-screws, and pressing against the revolving axle. E and E′ are pieces of metal connected one with each end of the coil. During one half revolution E′ is rubbing against *r*, as shown in the figure, and E against *r′*. We will suppose that during this time the current is passing from E′ through the external circuit to E, so that positive electricity is collected by *r* and negative by *r′*. During the next half revolution E will be rubbing against *r* and E′ against *r′*, so that if the current in the coil had not undergone reversal the current in the external circuit would be reversed. But the current in the coil is reversed

at the same moment that these contacts are reversed, thus the current in the external circuit is always i[n the] same direction. The spring r always [col]lects positive and the spring r' always [nega]tive electricity. This apparatus for coll[ecting] currents always in the same directi[on is] called a *commutator.*

Fig. 196.—Siemens' Armature.

393. If it is desired to employ the m[achine] for heating small pieces of wire, th[e coils] should be of moderately stout wire; b[ut for] decomposing water or giving shocks th[e wire] of the coils should be very fine, s[o that] there may be room for a great lengt[h of it.] A great length of fine wire gives the g[reater] electromotive force. The revolving [electro-]magnet is called an *armature.* Som[etimes] two different armatures are provid[ed, one] with thick and the other with thi[n wire.] The former is then called a *quantity* ar[mature,] and the latter an *intensity* armature.

394. An improved form of re[volving] electro - magnet, called **Siemens' armature**, is represented, with its commutator, in figs. 196 and 197; and fig. 198 shows a cross section of it, as it is mounted in its place in a machine where it revolves between the two poles A B. Its advantage lies in its c[ompact]ness, which allows the whole of it to be plac[ed]

Fig. 197.—Commutator.

ion of very strong magnetic force. Its construction very like that of huttle, iron tak- the place of od, as shown at , fig. 198, and e the place of ead. The iron ne is to be re- ded as the core of electro-magnet, d a and b are its es. They ex-

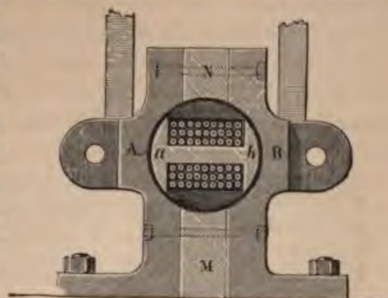


Fig 198.—Section of Siemens' Armature.

d along its whole length, and the poles A B of the el magnet extend the same distance.

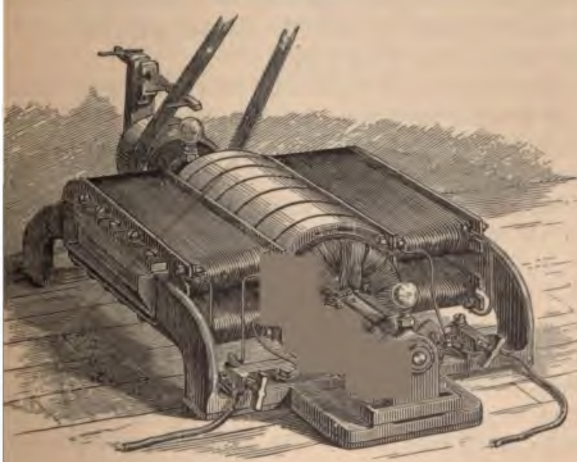


Fig. 199.—Siemens Direct-current Dynamo.

395. Fig. 199 represents one of the modern magneto-

ELECTRIC CURRENTS.

... The dynamo is ... the machine which ... This class ... these ... the smallest current ... Machines of this kind are ...

A third plan, ... the current for the field-magnet ... machine, which may be ... have ... magnets to produce ... powerful ... have their field magnets excited ... Dynamos with a separate exciter; the other two ...

398. In a self exciting dynamo, the current ... with a ... because the field-magnets have ... any ... in their cores ... and the current would not begin ... magnetism at all, but the little magnetism that is ... suffices to give a little current, this current makes the ... magnets stronger, and they in their turn make the current ... After a thousand revolutions or so, the ... have become as strongly magnetized as any current ... make them. They are then said to be *saturated*, and the current thenceforward remains steady.

399. A machine with only the single Siemens armature of fig. 196 gives a very jerky current; but when the sections of the coil and segments of the commutator are numerous, as in the machine of fig. 199, the current is ... uniform.

400. Another kind of armature, called the **Gramme ring** or the **Pacinotti ring**, is employed in the machines shown in figs. 202, 203. We shall explain it by reference to ... If an iron ring like an anchor ring, with

wire coiled round it, revolves in the direction of the arrows between the poles P P′ of a magnet, there will be poles induced in the iron ring at F and D, the points immediately opposite P and P′. As these poles remain fixed in space, while the iron ring in which they are formed revolves, it is clear that they must travel backwards through the iron of the ring. By so doing they generate currents in the surrounding coil on the same principle as in the experiment of fig. 193. As one is a north and the other a south pole, they generate opposite currents, which destroy one another if no way of escape is provided; but if collecting brushes rub on the wire at C and E, positive electricity will be given off at one of these points and negative at the other.

Fig. 201.

401. Practically, instead of the brushes rubbing on the wire they rub on the segments of a commutator, and the coil is divided into pairs of opposite sections, which are connected with these segments. The sections of the coil are very plainly shown in fig. 202, being represented dark and light alternately; the two brushes[1] rubbing one on the upper and the other on the under side of the commutator are also very distinctly seen. The field-magnet consists of several thin steel plates of horse-shoe form, with a pair of soft-iron pole-pieces, so shaped as nearly to surround the revolving ring. The core, instead of being solid like an anchor ring, is made of iron wire, so that it really consists of a multitude of rings.

[1] The so-called brushes are really flat bundles of wires, and the rubbing is not against the end but against the side.

402. Fig. 203 is a self-exciting dynamo constructed on this principle, the field-magnets being at top and bottom with the revolving armature between them. The latter is driven by a belt from a steam engine, which passes round the drum or pulley seen at the left hand. The

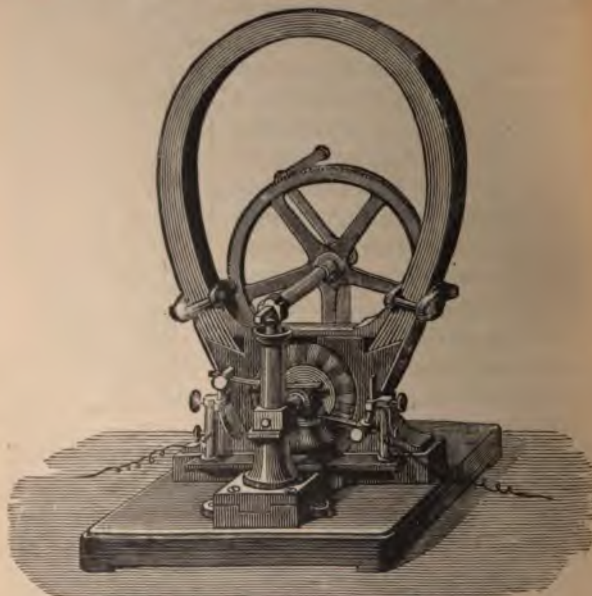


Fig. 202.—Gramme's Magneto-electric Machine, for hand-power.

arrangement of the poles of the field-magnets is the same as in the Siemens dynamo of fig. 199.

403. All these machines give a continuous current in one direction, and are called *direct-current* machines.

There is another class of machines giving currents first in one direction and then in the opposite, the reversals taking place some hundreds of times in every second.

have seen, in fact, in our study of the simplest ns of magneto-electro machine (art. 391), that the ent in the coil is continually reversed; and the same ue of the currents in the armature-coils of all the other hines that we have described. It is therefore a

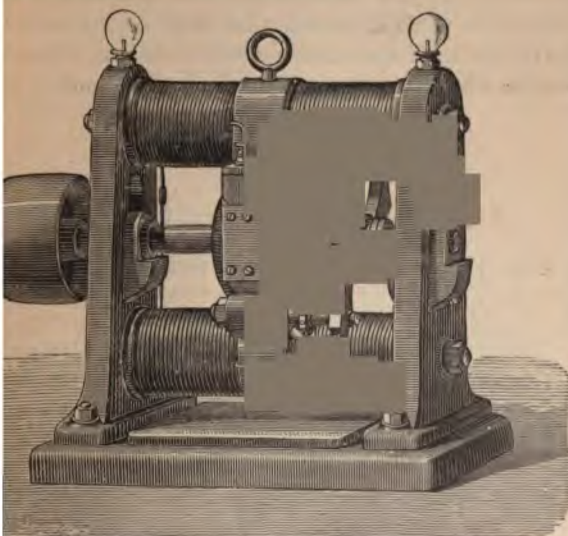


Fig. 203.—Gramme's Dynamo-electric Machine, for steam-power.

ler matter to collect alternating currents than to ct direct currents.

lternate-current dynamos are never self-exciting, for magnets will not do their duty if their magnetism is inually reversed.

)4. Dynamos are now used for all purposes for which ong current is required. They have completely super- d galvanic batteries for nearly all purposes except

telegraphy, as they furnish electricity in large quan
at much less expense. They are used not only for el
lighting and the driving of electro-motors, but als
electrotype and electroplating. When intended for
latter purpose their armatures are made of very
wire with very few convolutions, so as to have very
resistance; while if intended for maintaining a seri
arc lights, their armatures must have a great numb
convolutions, so as to give very high electromotive f

CHAPTER XXXII.
ELECTRIC LIGHT. ELECTROMOTORS.

405. The electric lights of the present day are di
guished into two kinds—**arc** li
and **incandescent lights.** Th
mer are exceedingly dazzling,
are apt to be fitful and flicke
the latter are extremely stead
pleasant, but do not yield ne
much light for the same cost.
have been only recently inve
whereas the arc light was exhi
by Sir Humphry Davy at the b
ning of this century.

406. We shall describe the in
descent light first, because it i
simplest. One of the lamps is r
sented in fig. 204. The light is
duced by sending a current thr
a thread of carbon, which is
[illegible] a white heat. If this were done in air the ca
[illegible] burn away, uniting with the oxyg

the air as coal does in the fire. To prevent this
bon filament is inclosed in a vacuous vessel of glas
vacuum of an ordinary air-pump would not be good
it is necessary to obtain the best vacuum possi
this is done by employing Sprengel's mercurial ai
at the same time heating the glass to drive off
the film of air and moisture which adheres to
cold. The current is conveyed to the carbon fila
means of two wires, which are sealed into the
the bottom of the lamp.

407. The **arc light,** which until recent years
only kind of electric light brought into use, is p
by employing two rods of carbon, letting them t
a moment so as to complete the circuit and al
current to pass, and then separating them to a small distance. They do not begin to heat until they touch, the resistance of cold air to electricity being sufficient to prevent any discharge from taking place across; but as soon as they touch they are rendered intensely hot by the passage of the current; and as hot air is a conductor, the current is able to pass across
the small space between them after they are se

Fig. 205.—The Carbons Magnifi

408. Fig. 205 shows the shape that they assun
the current passes steadily in one direction—name

the upper carbon to the lower one. The positive carbon becomes hollowed out like a saucer, while the negative carbon becomes comparatively sharp. The hollow in the positive carbon is the place of greatest brightness; and as the lamp is usually high above people's heads the positive carbon is placed uppermost that people may have the benefit of the light from the bright *crater* (as the hollow is sometimes called). The air between the points is intensely luminous, as well as the points themselves, and the bright streak formed by it is called the "electric arc," hence the name of *arc* light.

Bright particles pass across from the positive carbon to the negative; and the positive carbon is found to be consumed about twice as fast as the negative. When the current supplied is alternating both carbons wear away alike.

409. It is important to keep the carbons at exactly the right distance apart. If the distance varies the light will flicker, and beyond a certain distance it will be extinguished, in which case it will not begin again till they have touched once more. Arc lamps contain machinery of some kind for effecting this regulation. It differs very much in different lamps, and generally depends in some way on the two following principles:—(1) that as the points get further apart the current is weakened by the increased resistance thus introduced; and (2) that an electro-magnet gets stronger or weaker as the current round it gets stronger or weaker.

Electromotors.

410. We have now to explain another application of electric currents, which has taken a practical shape in recent years, and promises soon to become very important —the employment of electric currents to drive sewing-

machines, circular-saws, lathes, tricycles, tramcars, or anything else that requires forcible rotation.

In such applications a special machine called an **electromotor** is employed, so contrived that one portion of it is set in rotation by a current.

411. One of the earliest kinds is represented in fig. 206.

There are four double electro-magnets, two of which are seen to the left and right and the other two under-

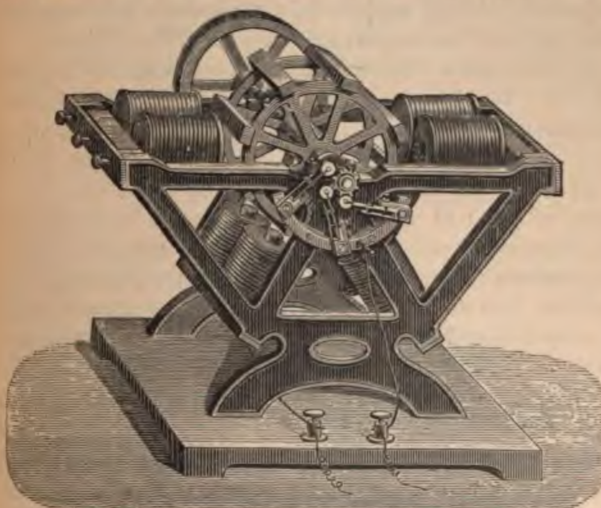


Fig. 206.—Froment's Electromotor.

neath; and the revolving frame between them has on its circumference a series of flat iron bars, which pass close in front of the feet of the magnets without quite touching them. Each magnet is made when a bar is approaching it and unmade just as the bar gets opposite to it, so that the attractions of the magnets, one after the other, on the

[illegible] from the sending station, along the line [illegible] binding-screw [illegible], and passes [illegible] of the electro-magnet [illegible] to another [illegible]. Thence it goes to the iron [illegible] through the contact-spring *q*, to [illegible] screw [illegible] through another wire to earth. [illegible] is of very brief duration: for the [illegible] as soon as it is made, attracts the cylinder [illegible] contact-spring, thus interrupting the [illegible] at the same time delivering a blow of the [illegible] K against the bell T. The current being inter- [illegible] is unmade, and the hammer flies [illegible] place, the lower end of its handle [illegible] spring, which urges it back. But as [illegible] contact-spring, the current comes [illegible] is again jerked forward. It [illegible] till the current is turned [illegible] the message is sent.

[illegible] of sending the message. The [illegible]. The lever A and the [illegible] are of brass, the points [illegible] of brass, the stand [illegible] by pressing down [illegible] the finger is removed the [illegible] again. The lever is in per- [illegible] its supporting pillar with [illegible] it with other stations. [illegible] shown in the figure, the lever is [illegible] wire R, which leads from [illegible] it is left in this position [illegible] from another station.

When [illegible] K is pressed down, [illegible] comes into con- [illegible] with [illegible] and the lever is thus brought into connection with the wire P, which leads to the battery. As

cordingly, so long as the key is down, the battery is in connection with the line wire; and as long as the key is up, the connection is broken. Currents are therefore sent by pressing down the key, and stopped by letting the key spring up again; and each current will last just as

Fig. 208.—Morse's Key.

long as the operator keeps the key pressed down. In sending messages, there are two lengths of signal employed. One of the two is as short as it can be made, and is called *dot;* the other is a little longer, and is called *dash.* They can in fact be made to print dots and dashes on a strip of paper, at the station at which the message is received.

418. In the telegraphic alphabet, each letter is represented by its own special combination of *dots* and *dashes*, according to the following scheme:—

MORSE'S ALPHABET.

A ·—	K —·—	U ··—
B —···	L ·—··	V ···—
C —·—·	M ——	W ·——
D —··	N —·	X —··—
E ·	O ———	Y —·——
F ··—·	P ·——·	Z ——··
G ——·	Q ——·—	
H ····	R ·—·	Understood ···—·
I ··	S ···	
J ·———	T —	

412. We will now trace the action of these cu
the receiving station.

Fig. 209 represents one of the simplest forms o
ing instrument—the Morse **recorder.** The c
enter by one binding-screw, and, after traversi
coil of the electro-magnet, go out through the
binding-screw to earth. The electro-magnet, when
is made, pulls down by its attraction the short arm

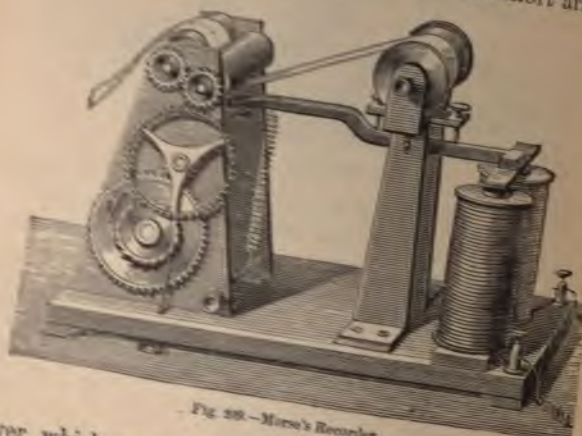


Fig. 209.—Morse's Recorder.

lever, which carries, for this purpose, a flat bar of iron,
just above the cores of the electro-magnet. The long
arm of the lever is thus forced up, and a writing point
which it carries is forced against a moving strip of paper,
which is thus written on or indented. An opposing spring
pulls down the long arm of the lever as soon as the
current stops, and there are two adjustable screws over
the lever, for regulating the amount of its play, which is
always very small. The strip of paper is drawn uniformly
on by clockwork, so that the length of the scratches

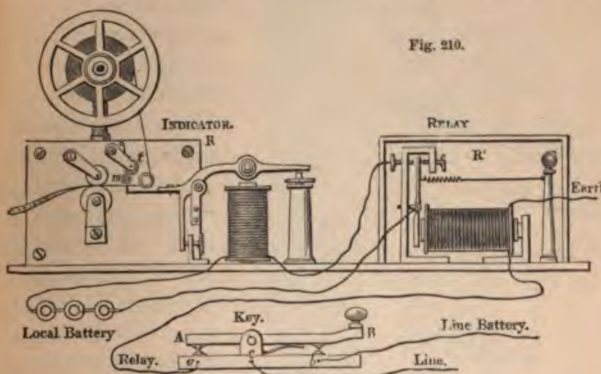
made by the writing point is an index of the length of time the currents last.

More frequently, instead of a scratching point, there is an *ink-writer* consisting of a sharp-edged wheel, which writes with its edge, and is kept inked by means of a roller covered with a kind of printing ink.

The messages can be heard as well as seen, and very often they are read off by ear without any recording apparatus. A dot is heard as two blows near together, and a dash as two blows with a longer interval between.

420. Great use is made, in telegraphing over long distances, of an apparatus called a **relay,** which is well illus-

Fig. 210.



trated in fig. 210. Its object is to make strong currents take the place of weak ones. Currents which have travelled so far as to have lost much of their strength arrive by the wire marked "line," enter the key at c, pass out at a, and then through the electro-magnet of the relay to earth. This electro-magnet has the duty of moving a small upright lever through a very small distance, just far enough to make the upper end of the lever move across from one

of two stops to the opposite one. It thus co circuit of a battery kept for this purpose, cal *battery.* When the current from the line stop lever in the relay is pulled back by a very we spring, and the current of the local battery is The weak currents from the line are thus re the shape of the strong currents of the lo which may be employed to work a Morse rec the figure, but are also very frequently employ

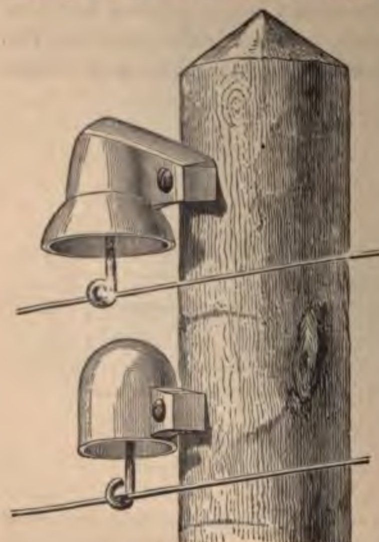


Fig. 211.—Insulators.

on the other hence the from the relays of

421. wires ar kinds—ai undergro

Air wi pended o means of which ar porcelain, like inve One form shown i The insi cup is no rain, and cordingly, a considerable breadth of dry su which the electricity would have to pass bef escape.

Underground wires are covered with a pr gutta percha and buried in iron pipes, from

can be drawn out when examination is necessary. They have the advantage of being unaffected by snow-storms and gales of wind, which often cause a complete interruption of telegraphic communication when air lines are employed; but they are less favourable for quick signalling, owing to the *induction* which takes place between them and the earth by which they are surrounded.

422. It is not usual to employ two wires, so as to have a complete metallic circuit, in sending telegraphic currents. A single wire suffices; but the battery which sends currents into the wire from one of its terminals must have its other terminal connected with the earth, and it gives as much electricity of one kind to the earth as it gives of the other kind to the wire.

The receiving instrument must also have a wire leading to the earth through which the current can escape after doing its duty. The best earth-connections are obtained by soldering the earth-wires to the large iron pipes which supply towns with water. Failing these, an iron pump or iron gas-pipes may be used; and when none of these are available, the earth wire is usually soldered to a large plate of iron buried in the earth at a sufficient depth for the soil round it to be always moist.

423. Velocity of Electricity.—The velocity with which electricity travels along a wire cannot be stated as definitely as the velocity with which sound or light travels through the air.

When the distance is great, and the wire is buried in the earth or in the sea, it is found that, on putting one end of the wire into connection with a battery, the effect at the other end does not begin suddenly, but gradually increases from nothing to its full strength. The earliness of the first observable effect will therefore depend very much upon how weak a current the receiving instrument

is able to show, and also very much upon the violence of the original disturbance: for example, the discharge of a Leyden jar or a Ruhmkorff coil would produce an earlier indication than a current from a galvanic battery.

It is not necessary, in making such observations, that the two ends of the wire should be far apart, for, by employing a return wire, we may have them in the same room, although the current has to cross the Atlantic and return.

The signals will be received earlier if the wire be not submerged but suspended in the air; and Wheatstone, by employing two coils of wire a quarter of a mile long, and discharging a Leyden jar through them, found a velocity much greater than that of light. His experiment is memorable, not only as being the earliest measurement of the velocity of electricity, but still more for his ingenious device of "the rotating mirror," which has ever since been recognized as an important instrument of physical research. We have described one of its applications in art. 244.

CHAPTER XXXIV.

RUHMKORFF COIL. TELEPHONE.

424. We will now describe an instrument which is very much used for producing electric sparks. It is called Ruhmkorff's induction coil, and its external appearance is shown in fig. 212. The following is its construction: b and b are two binding screws for attaching wires from a battery. They are the terminals of a coil of moderately stout wire called the *primary coil*, which surrounds a core consisting of a bundle of straight iron wires. The end of the core is visible in the figure. The circuit is made and broken by the movements of the portion of the apparatus shown at L, which vibrates to and from the core whe

the instrument is working. The circuit is completed by the dipping of a point into the mercury M, and is broken when this point leaves the mercury as the piece swings over towards the coil. Very often, instead of a point dipping into mercury, there is a platinum point which makes contact with another piece of platinum. The principle, in

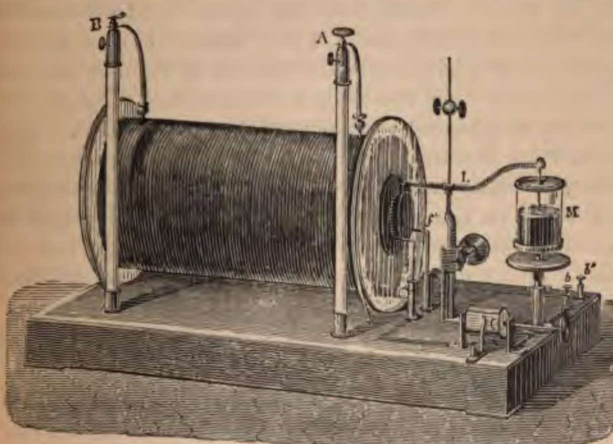


Fig. 212.—Ruhmkorff Coil.

either case, is the same as in the telegraphic alarum which we described in art. 416, the movements being produced, as there, by the attraction of the core when the current passes and the elastic rebound of a spring when the current stops.

425. Outside this primary coil is wound a much longer coil—often some miles long—of very fine wire, called the *secondary coil*, and it is this secondary coil that gives the spark. It sends come to the brass terminals A and B, which have binding-screws, to which two short wires are usually attached, and between the ends of these wires, if

[illegible] a spark will pass every time [illegible] If, instead of taking a spark [illegible] join their ends so as to close the [illegible] there will be a current in one direction [illegible] by the sudden magnetization of [illegible] current in the opposite direction produced [illegible] demagnetization; but owing to an action [illegible] which is very marked in coils with a [illegible] the current at making is com- [illegible] its origin and cessation, whereas the [illegible] is extremely short and *sudden*. The [illegible] electricity passes in both cases, but [illegible] electromotive force in the second [illegible] first. Accordingly, the spark which is [illegible] terminals of the secondary coil in [illegible] of the instrument is obtained only on [illegible] the primary circuit.

42[illegible] [illegible] of the apparatus is seen the [illegible] spring pressing against it [illegible] By turning this the [illegible] be turned on and off, and can [illegible]

[illegible] a shock from a Ruhmkorff coil [illegible] shock from one will cause a person [illegible] unless the coil is very small.

427 [illegible] is very much used for showing [illegible] rarefied gases. An electromotive [illegible] a quarter-inch spark in air at at[illegible] pressure, will give a spark about a foot long in [illegible] air or any highly rarefied gas; and glass [illegible] manufactured which, after having platinum [illegible] into them at both ends, are filled with some gas and then hermetically sealed. The terminals of the secondary coil are connected with the two platinum wires

and as soon as the current of the battery is turned on, the discharge passes. The light is too faint to be well seen by daylight, but it presents a beautiful appearance in the dark, and bears a strong resemblance to the aurora borealis.

428. We will now give some account of the means by which speech is reproduced at a distance in the **telephone.**

We will first describe the receiving instrument. Fig. 213 represents the form of it originally introduced by

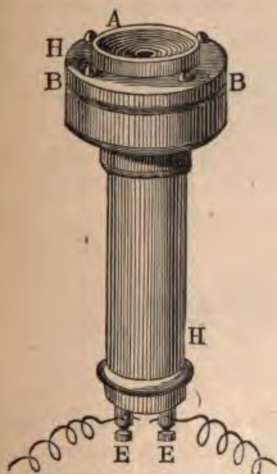


Fig. 213.—Telephone.

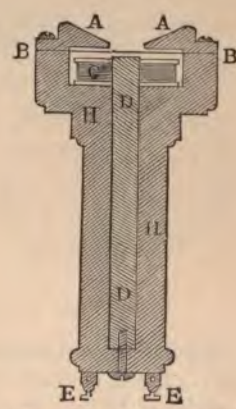


Fig. 214.—Section of Telephone.

the chief inventor of telephony, Professor Graham Bell, and fig. 214 is a section.

D D is a steel magnet of cylindrical form, and C is a coil of extremely fine copper wire surrounding one end of it, the two ends of this coil being in connection with the binding-screws E E. A current passing in one

direction will strengthen, and in the other direction will weaken the attraction of the magnet upon the thin iron plate B B, called the *diaphragm;* and if the currents succeed each other with sufficient quickness, the small movements of the plate to and from the magnet will give rise to sound, which may be heard by a person placing his ear at the opening A A.

429. If we connect the two binding-screws with a battery, we hear nothing so long as the current is steady; but when it is suddenly interrupted by breaking connection, we hear a sound from the diaphragm, loud enough

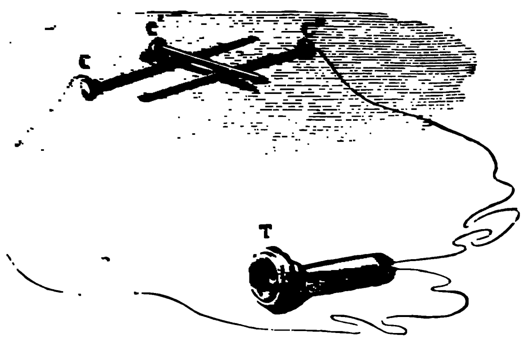


Fig. 213.—Principle of Microphone.

to be heard at a distance of some yards; and a similar sound is heard at the moment of making connection. If we make and break connection by means of a vibrating spring which makes 500 vibrations per second, we hear a note of 500 vibrations per second, because the diaphragm makes the same number of vibrations as the spring, being compelled to do so by the varying attraction of the magnet.

430. If we arrange a circuit as in fig. 215, where P is the symbol for a battery, T is a telephone, and C C′ C″ are

three bright copper or brass nails, one of which completes the circuit by resting on the other two, sounds will be audible in the telephone not only when this nail is lifted off and put on again, but also when it is made to tremble by any kind of disturbance. The sounds are produced in this last case by variations of resistance at the points of contact of the nails, a resistance which is considerable by reason of the smallness of the area of contact, and the intervention perhaps of a thin layer of air. This resistance is diminished by pressing the nails together, and increased by relieving their pressure, so that any up-and-down trembling causes variations of the current; and these cause variations in the attraction of the magnet upon the diaphragm. The sounds thus produced are not audible at a distance, but they can be heard by holding the telephone to the ear. An arrangement of this kind is called a **microphone**, and instead of employing a metal for making the contacts, it is found better to use carbon.

431. This is the principle of the sending instrument in all the best telephones now in use.

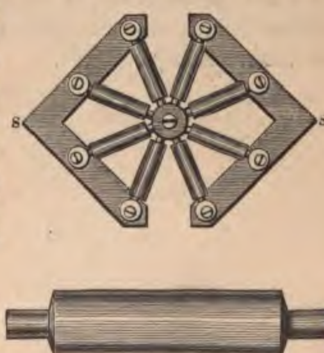


Fig. 216.—Part of Sending Instrument.

Fig. 216 shows how the carbon contacts are arranged in the Gower-Bell pattern. Eight sticks of carbon, one of which is shown full-size at the bottom, have their ends loosely inserted in holes in carbon blocks. Four of these blocks are attached to a strip of copper S, four others to a similar strip on the other side S′, and another

block with 8 holes in it stands in the centre and is insulated. The current from the battery has to pass from one of the two copper strips to the other through the carbons; and the copper strips and central block are fastened to the under side of a thin board, which is shaken by the voice of the speaker. The variations in the current thus represent, with more or less exactness, the variations in the pressure of the air produced by the speaker's voice; and if a telephone is included in the circuit, its diaphragm will give forth an imitation of the spoken sounds. It is found, however, that more distinct speech is obtained by the addition of a small Ruhmkorff coil (see art. 424). The variable currents which we have been describing go through the primary coil, which has no direct communication with the line wire, and the currents which are transmitted to the receiving station are the secondary currents.

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